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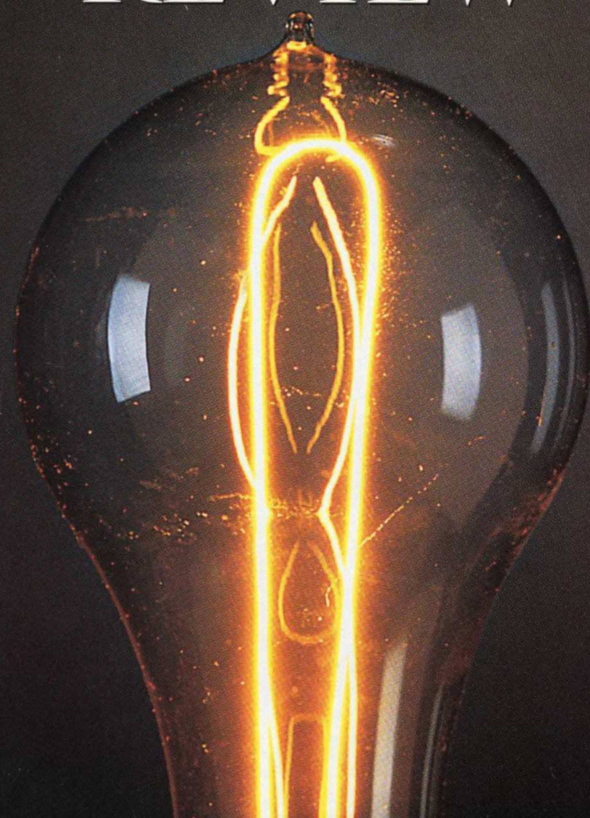

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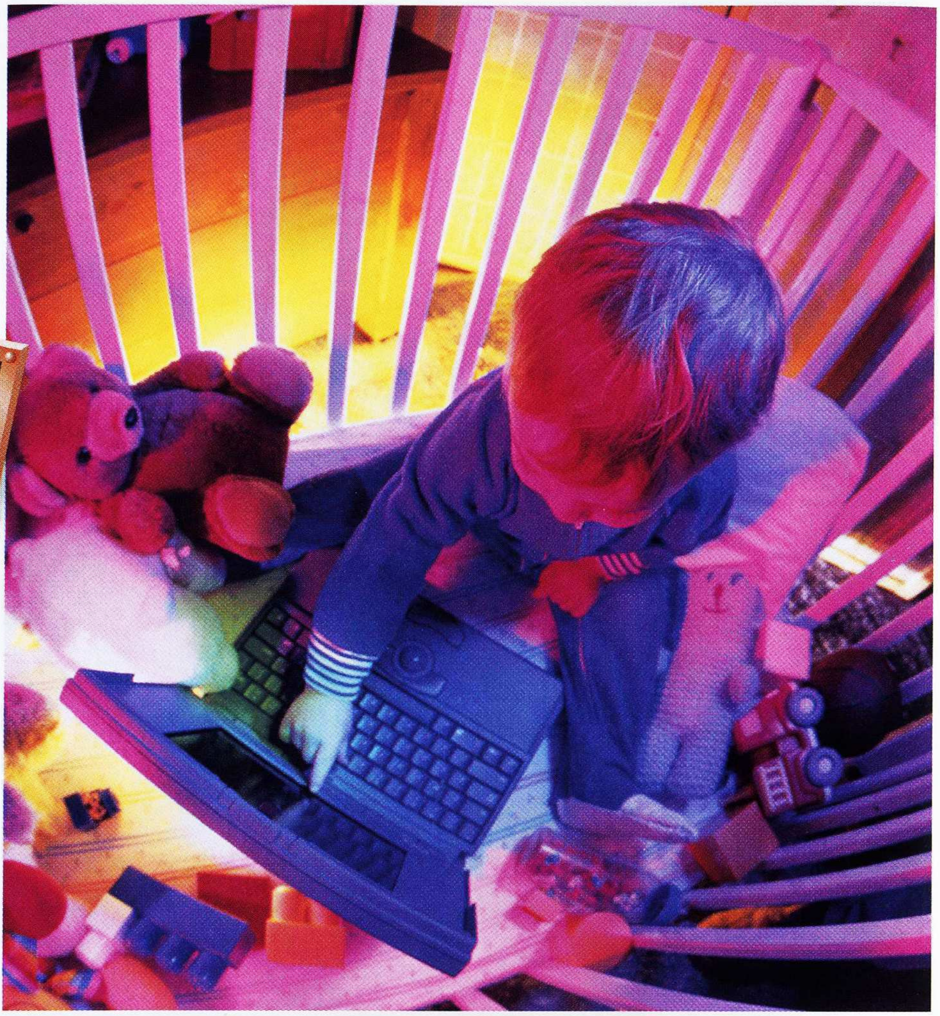

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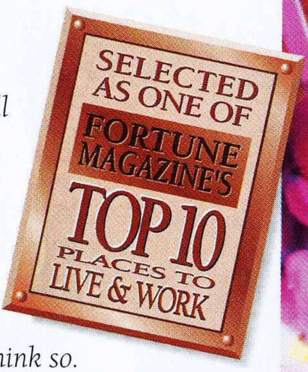

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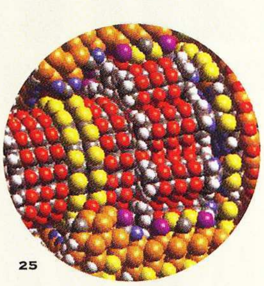

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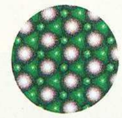

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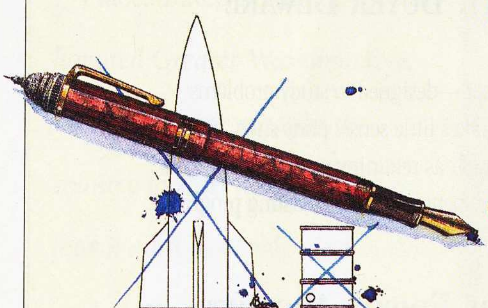

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First Line

Just Rewards

"I'd like to thank my producer, my crew, the cast, the studio, my wife, . . ."

At this time of year, vivid images begin to dominate my daydreams: a glamorous couple—elegant woman in an evening gown, handsome guy in a tux—comes to the dais and begins to address an audience full of similarly beautiful people (among them yours truly—well coiffed and clad, and so deftly enhanced I'm practically a Mel Gibson look-alike). The pair exchange some lighthearted banter and quickly get down to business. "The envelope, *please*. The nominees are: magazine A, magazine B, . . . , and *Technology Review*."

In synch with each publication's name, cameras pan on the corresponding editors. When *Technology Review* is mentioned, I show up on your television screen pensive but detached; my face flashes a hopeful but not desperate, confident but not cocky grin to the millions of viewers in TV land. As the audience awaits the verdict, time seems suspended like the hands on Salvador Dali's melted watches. "And the winner is: *Technology Review*!" Stunned and grateful, I explode with joy. My chic wife gives me a big kiss, my sartorially splendid *TR* colleagues exchange delirious hugs. I proceed to the stage to deliver a stirring acceptance speech.

In the days, weeks, and months after the ceremony, I am a guest on the *Tonight Show,* profiled on *60 Minutes*, and interviewed by David Brinkley. Geraldo begs for some time, too, but to no avail. Meanwhile, *Technology Review* as a media phenomenon—a "hot book," as we say in the trade—is a page-one story in the *New York Times*. Every reporter worth his or her salt scrutinizes each new issue for a possible wire-service scoop or a feature on the evening news about the latest and greatest in our now-sexy beat of "technology and its implications."

My colleagues at *Technology Review* and our institutional parent—MIT—revel in household name recognition, good vibrations, and carte blanche from all our constituencies and would-be patrons. Our editors vie with the Henry Kissingers for lecture-circuit status, and MIT soon acquires, even surpasses, the durable mystique of our ivy-covered academic neighbor down the street. Faculty and students at the Institute, and everyone associated with it, however tenuously, attain instant celebrity status as smart, cool, and enlightened.

Decades later, as an emeritus editor in the winter of his years, I receive the journalist's equivalent of the Irving G. Thalberg Award for lifetime achievement among film producers. At this sumptuous prime-time-TV affair, I avuncularly puff on my cigar and tell amusing anecdotes about the magazine business. The nation likes me. It really, really likes me.

And not just me. *Technology Review*, by this time, has been repeatedly chronicled in all the best books and anointed by all the high priests of culture. We are the cat's meow, *de rigeur* reading for the world's movers and shakers. And eager subscribers and advertisers, trying to tap some of the magic, are breaking down the door.

This series of escalating, obviously out-of-control fantasies is triggered by the prospect of a National Magazine Award—the Oscar of the magazine business—applications for which are due right about now. The awards ceremony itself takes place in April. But even though it's held at New York's posh Waldorf-Astoria, I can't be sure if the actual event resembles the celebrated Hollywood pageant because I've never attended. Though *Technology Review* has twice been nominated, it hasn't yet been so honored on my watch. Clearly an oversight, don't you think? And in those two earlier shots at immortality (sharing that finalists' circle with only four or five among all the nation's magazines), it didn't win. Thus *TR* has yet to experience the award's aftermath (with or without my fanciful projections).

But I grew up in Brooklyn when the Dodgers, the renowned Boys of Summer, were holding sway. They, too, had been "nominated" a few times (with a National League Pennant) but had not yet won a World Series. (I have a baseball-oriented fantasy, too, for *TR*'s ultimate recognition and glory. Briefly, we are the 1950s Yankees, who won five World Series in a row. I, of course, am manager Casey Stengel.) The Dodgers eventually did win the top prize, and after dem bums moved to Los Angeles they went on to win it five more times. Yet while they were perennially failing to bring the greatest of baseball honors back to Brooklyn, the fans were aghast and heartbroken but ever hopeful, repeating the refrain "Wait till next year."

Those are essentially our sentiments at *Technology Review* as well. Despite our studio/stadium full of star performers—the colleagues with whom I'm privileged to work are, I believe, the Meryl Streeps and Jackie Robinsons of the business; and we like to think we regularly produce the equivalents of *Sophie's Choice* and crowd-thrilling plays—the big prize of our field, that ultimate recognition by our peers and then the world, still lies before us. So each year we choose what we expect will rank well among other magazines' finest efforts, and then hope for the best.

And though you might see it first when the American Society of Magazine Editors—the rough equivalent of the Academy of Motion Picture Arts and Sciences—advertises its slate of magazine "academy award" winners in newspapers next April, I hope to tell you shortly thereafter that this is our year. Of course, I don't really expect the earth to reverse its spin when that happens, but such an honor might at least confirm two things: that the coverage of science- and technology-related affairs is of critical importance; and that reading about it, in our pages and elsewhere, is accepted and enjoyed by not only the cognoscenti but the general public.

But whether we receive a National Magazine Award this year or some other year or maybe never ever, I promise that we will always endeavor to present award-worthy material to our readers in every article of every issue. Our main reward is that you continue to like and find useful, year in and year out, what you see in these pages. That's "winner" enough. ■

—Steven J. Marcus

Letters

IN FROM THE COLD

I was delighted to read Seth Shulman's "Code Name: Corona" (*TR October 1996*), which nicely captured the intensity and creativity of the unique group of engineers and scientists who created the top-secret U.S. spy-satellite program during the height of world tensions in the late 1950s and 1960s. As an Itek engineer who worked on the program, I can attest to the dogged persistence of those involved.

However, the less-than-favorable references to the National Reconnaissance Office (NRO) warrant comment. While the NRO does have a large classified budget and probably remains more secretive than necessary in today's political climate, the NRO and CIA are conducting a review that will lay the groundwork for future declassification of Corona's follow-on satellite systems.

The NRO has made significant but often unrecognized contributions. To assess cloud cover in advance of Corona's transit, the NRO developed the first weather satellites, which have since evolved into the weather-satellite images used on TV news programs. In quiet but active relationships over the years with numerous government agencies, including the Department of Defense, the Department of Energy, and the Environmental Protection Agency's Strategic Environmental Research and Development Program, NRO intelligence has been used to monitor hazardous-waste sites and ecological indicators of global changes. The NRO is now working with researchers at Harvard University to apply its satellite image-enhancement technologies in the early detection of breast cancer.

RICHARD J. WOLLENSAK
HDOS-Itek Reconnaissance Systems
Lexington, Mass.

As a satellite meteorologist, I was disappointed that the author did not cover the vital role of weather in the Corona program. From 1967 to 1970, I was in charge of forecasting the weather for efforts to retrieve the film cannisters ejected from the spy satellites. It was one of the most difficult and complicated

A "Go" on a New Logo

Technology Review's cover design has changed many times over its 98-year history, as the accompanying display in our office attests. Readers may notice in this issue yet another new cover look—specifically in the "logo" that conveys the magazine's name and that of its institutional base, MIT. The goal was to modernize the logo, making it lively and easier to read, yet also to convey a dignified—"classic"—impression. And we wanted to remind readers, up top and unambiguously, of our distinguished sponsor. We acknowledge our new publisher, Bruce Journey, for prompting this initiative (as well as others you'll experience in the months ahead) and the *TR* staff for its numerous thoughtful suggestions. But we especially thank Kathy Sayre, our design director (appearing in the photo with her predecessors' work, as well as some of her own), for accomplishing the difficult logo redesign with professionalism, distinction, and—we hope readers will agree—success.

PHOTO BY L. BARRY HETHERINGTON

weather jobs of all time. Clear skies were not the ideal situation for the pilots. Ironically, a low-scattered cloud deck was necessary to provide a horizon for the C-130 pilots attempting to catch the parachuting cannister at 12,500 feet.

Our best forecasting tool was a secret U.S. Air Force weather satellite called the Defense Meteorological Satellite Program (DMSP), formerly known as P-417. Because I got my training in DMSP imagery in Vietnam, I thought the classified satellites were being launched to support the war. They were, but their primary purpose was Corona.

HANK BRANDLI
Melbourne, Fla.

"Code Name: Corona" brought back memories of a simpler but colder era. However, I was surprised at the claim that "four [of the first eight launches] did not even achieve orbit." As the engineering manager responsible for the Agena rocket engine on board the Corona, I certainly would have been called on the carpet for any failures.

The only failure I knew of occurred further along in the program when, prior to a launch and without authorization, the prime contractor removed the insulation surrounding the engine's exhaust, resulting in overheating.

I might add that Agena was not just a spacecraft, as the article implies, but, as the second stage of the Thor-Agena booster system, was a significant contributor to the velocity necessary to achieve orbit.

CLAYTON W. WILLIAMS
Sacramento, Calif.

Seth Shulman did a great job in "Code Name: Corona." But he slipped when he concluded that "secrecy not only needlessly keeps the U.S. public in the dark; it also leads to waste." I represented the Air Force on the inter-agency group that controlled the configuration of the Corona payloads. I helped to keep the second Corona mission, mentioned in the article, "a much quieter affair" than the first. I also accompanied the "CIA operatives posing as Air Force officials" on the mission to Caracas to recover film from an errant Corona capsule.

Concealing Corona was required to prevent the Soviets from reacting as they did when Gary Powers's U-2 spy plane was shot down. I am rather proud of the money we spent playing shell games with the Corona payloads.

If the whole program had been handled differently, we might now have international resolutions banning reconnaissance from space. Instead, there is a general acceptance of "national technical means of verification." The use of this euphemism in the SALT treaties indicates how sensitive the subject was considered. A high degree of secrecy to conceal our precise current capabilities is still required and will be for the foreseeable future.

BILL JOHNSON
Arnold, Md.

"Code Name: Corona" is a wonderful testament to the scientists and engineers involved in the program. However, the end of the article contains a misleading reference to the NRO's budget, specifically the "missing cache" of funds. In fact, this money was never missing; unspent, it was rescinded by Congress to be used for other purposes.

KATHERINE SCHNEIDER
Chief, Public Affairs Staff
National Reconnaissance Office
Washington, D.C.

REINVENTING THE WHEEL

I add to Sidney Perkowitz's wonderful article, "Hubs, Struts, and Aesthetics" (*TR November/December 1996*), my observation that wheel centers seem to reflect the times of their production.

We welcome letters to the editor.
Write: Technology Review, *Building W59, Cambridge, MA 02139. Fax: (617)258-8778.*
E-mail: <technology-review-letters@mit.edu>.
Please include your address, telephone number, and e-mail address.
Letters may be edited for clarity and length.

From the early days of the automobile through World War I, the emerging automobile technology stood upon awkward artillery spokes. Airy and carefree wire wheels mirrored the twenties and thirties. Automobile production of the forties—started, halted, and started again to get us through the war—offered get-the-job-done, domed chrome hubcaps identifiable only by the manufacturer's dog-tag inscription. As our hopes soared in the fifties, our visions of grandeur were parlayed into large and dominant chromium designs. The experimental sixties produced spinners and patterns, while cast wheels and grandiose disco designs reflected the seventies.

I have purposely left out the most recent years. Today's vehicles are the result of incredible advancements in technology, materials, and design. But we can no longer relate to our cars. We don't even perform our own car repairs. When was the last time you changed a flat tire and in the process studied your hubcap?

DAVID MACHAIEK
Owls Head Transportation Museum
Owls Head, Maine

As an antique-car collector, I was pleasantly surprised to see "Hubs, Struts, and Aesthetics." However, my reaction changed when I read erroneous information. Please note that in the caption on page 62, Dusenberg is misspelled. It is Duesenberg. The caption also refers to the Kissel Kar of 1926. The "Kar" part of the name was dropped by the company in 1919 to avoid association with Germany.

In the photos on pages 56 and 57, the hubcap linked to the Ford Model T is actually from a Ford Model A. In the fifth column, the steel-disk wheel is from a 1920s Dodge car, not from a 1930s Dodge Brothers one. The company name was changed when Chrysler bought it. Finally, in the seventh column, the second photo from the top is not of a wheel from a 1930s Ford truck. It looks like a modern alloy wheel of some kind, perhaps stuck onto an older truck. Nothing like that was made in the 1930s.

WILLIAM SHIELDS
Vienna, Va.

AN UNOFFICIAL RECORD

The first sentence in Mark Fischetti's "Breaking the Sound Barrier . . . in a Car" (*TR August/September 1996*) reads: "No one will remember the name of the second person to break the sound barrier on land." Apparently, the name of the first person to accomplish that feat has also been forgotten. Stan Barrett successfully drove a car at supersonic speed about 10 years ago. Ray Van Aken, at that time an aerodynamicist at the Naval Air Warfare Center/China Lake, helped solve some of the problems mentioned in the article. The car driven by Barrett is stored at the Smithsonian Institution. Its performance did not qualify as an official speed record since it did not traverse the course in both directions.

LEON SCHINDEL
Rockville, Md.

HOW MANY LAWYERS TO CHANGE A BATTERY?

"EVs: Clean Today, Cleaner Tomorrow" (*TR August/September 1996*) by Drew Kodjak epitomizes what is wrong with our clean-air efforts today: lawyers who think they know science and take charge of programs. According to Kodjak, "Solar panels on the roofs of houses could collect energy by day and use it to charge a spare EV battery. Once home, the motorist would simply exchange today's spent battery pack with a newly charged one." I would like to see the author change the 2,000-pound battery in the General Motors EV1. Perhaps this task would keep lawyers busy enough to keep them out of things about which they know nothing.

JAMES A. LIMA
Professor Emeritus
San Jose State University
San Jose, Calif.

WHAT STEWARDSHIP MEANS

I read with interest Kurt Repanshek's "Species Protection: New Incentives for Landowners" (*TR October 1996*). I agree that there is a "tragedy of the commons" phenomenon occurring here in that it's not in any landowner's short-

term financial interest to preserve his or her land in reasonably untouched condition. But shouldn't the benefits of owning land, a luxury out of reach for most of us, entail some responsibility for taking good care of it? Isn't that what stewardship means? Instead of paying owners not to trash their land, why shouldn't we establish a standard for land ownership that includes leaving it in good shape and protecting endangered species?

STEVE GASKIN
Sherborn, Mass.

THE NEED TO PRESERVE ELECTRONIC RECORDS

While "Wired Science" (*TR October 1996*) by Herb Brody reveals many of the advantages and disadvantages of using the Internet for science, one critical issue dodged by both the author and many proponents of electronic publication is the archiving of science.

Right now, I can go to the library and read exactly what a 19th century scientist observed when doing a geological report. What if I were alive in the 22nd century and wanted to learn what a geologist of the prior century had observed? If his or her observations had been self-published on the Internet, there would be an outstanding chance that they would no longer be available on the 22nd century computer network.

What's more, even if master archives of all Internet materials are kept, some will probably exist in short-lived applications. At least paper-based media never had such problems.

Finally, the ability to revise works—considered a strength of the Internet—may actually deprive future readers of information about the process of science. This is much like a geologic field guide that is constantly updated: prior observations are lost as only the most recent ones are saved.

My point is not to suggest that electronic publications are untenable. They will almost certainly serve as a superior replacement for print journals. But many electronic-publication schemes are little more than preprint distribution networks. While paper journals may well die, the media that replace them must extend the online research contribution beyond a few years. Mechanisms for making contributions permanent are needed.

CRAIG JONES
Boulder, Colo.

NAVIGATORS OF THE INTERNET

Thanks to editor Steven J. Marcus in "Ask the Librarian" (*First Line, TR November/December 1996*) for recognizing that librarians are master navigators of the Internet. Many librarians have already put what they know about the Internet online. Check out the August 1996 issue of *Internet World* for reviews of several sites by librarians, including my own guide to the best information on the Internet (<www.sau.edu/cwis/internet/wild/index.htm>).

MARYLAINE BLOCK
Associate Director for Public Services
St. Ambrose University Library
Davenport, Iowa

CORRECTION

In "Houses of Straw" (*TR November/December 1996*), the photograph of the finished straw-bale structure (page 18) was incorrectly credited. The photographer is Catherine Wanek. We regret the error.

Continued on page 73

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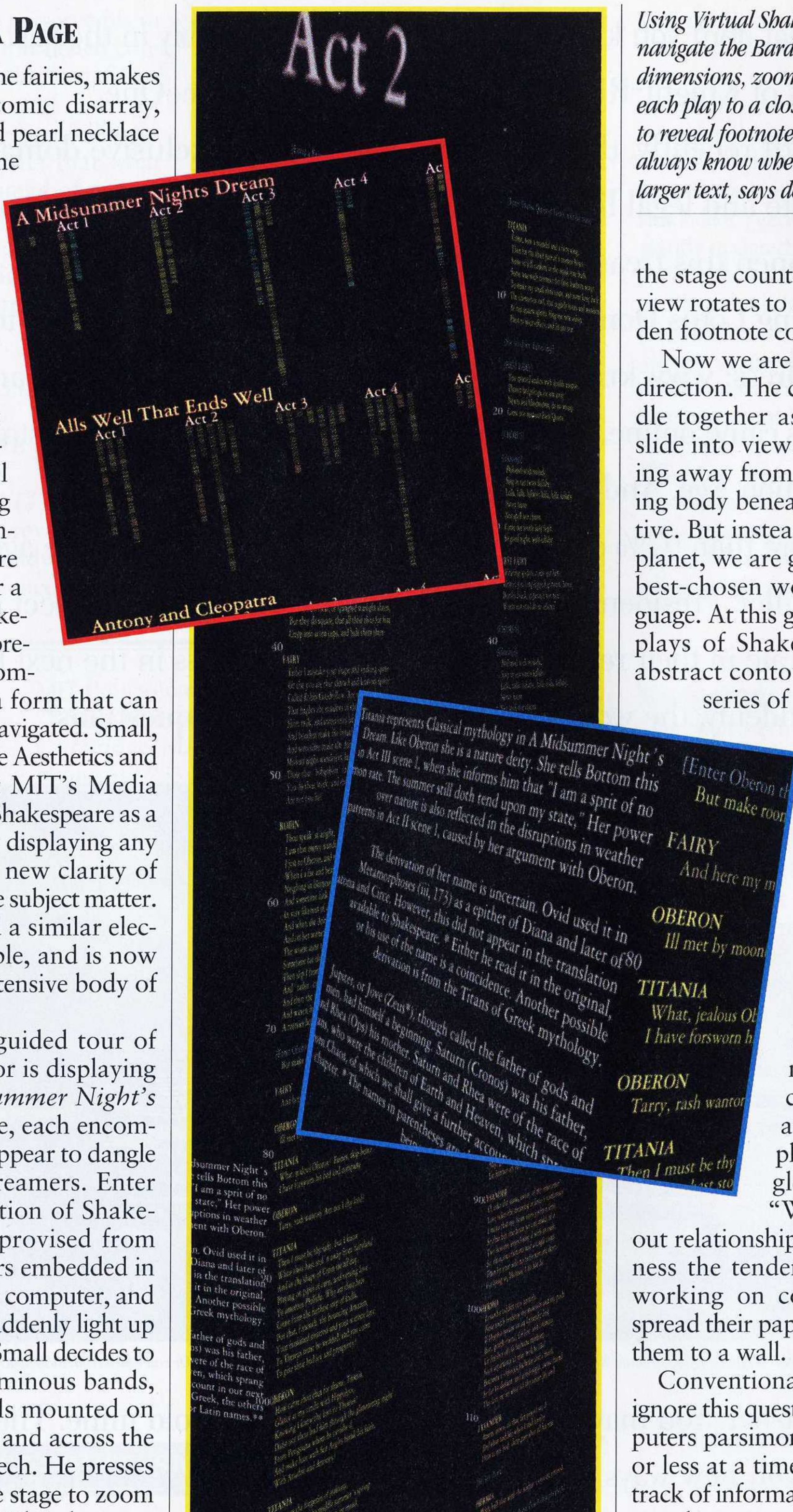
MIT Reporter

ALL THE WORLD'S A PAGE

Titania, queen of the fairies, makes her entrance in comic disarray, pink polka-dot dress and pearl necklace clashing fiercely with the back-turned baseball cap and rakish mustache adorning her plastic head. The footlights flash on as David Small places her on the hand-sized stage he has built from LEGO bricks. But the figurine and the stage are merely the control system for the real show, which is taking place on a nearby computer monitor. They are the Nintendo joystick for a project called Virtual Shakespeare, Small's effort to present the playwright's complete dramatic texts in a form that can be easily and intuitively navigated. Small, a doctoral candidate in the Aesthetics and Computation Group at MIT's Media Laboratory, sees Virtual Shakespeare as a step toward a system for displaying any large body of text with new clarity of structure, regardless of the subject matter. In fact, he has produced a similar electronic version of the Bible, and is now adapting some of the extensive body of Jewish sacred writings.

As Small begins his guided tour of Shakespeare, the monitor is displaying the full text of *A Midsummer Night's Dream*. Columns of type, each encompassing an entire scene, appear to dangle in space like ghostly streamers. Enter Titania, one of a collection of Shakespearean characters improvised from LEGO figurines. Resistors embedded in her feet identify her to the computer, and all her lines of dialogue suddenly light up on the computer screen. Small decides to head for one of these luminous bands, spinning a pair of wheels mounted on the stage to travel down and across the columns to a lengthy speech. He presses a button at the side of the stage to zoom in close enough to read. When he turns the stage counterclockwise, the plane of view rotates to display an otherwise hidden footnote concerning Titania.



Using Virtual Shakespeare, a reader can navigate the Bard's dramatic works in three dimensions, zooming from a global view of each play to a close-up that can be "tilted" to reveal footnotes. As a result, readers always know where they are within the larger text, says developer David Small.

Now we are zooming in the opposite direction. The columns shrink and huddle together as more and more plays slide into view. Like astronauts speeding away from earth, we see the glowing body beneath us with new perspective. But instead of looking out upon a planet, we are gazing at a million of the best-chosen words in the English language. At this global scale, the complete plays of Shakespeare are reduced to abstract contours. Each play is now a series of threadlike columns that preserve the order and relative lengths of scenes, and the grouping of scenes into acts, but are otherwise illegible.

By freeing readers so they can navigate a body of writing at any scale they may choose, Small hopes to bring the display of text into harmony with human perception. "People are good at taking in a lot of complicated structure at a single glance," he explains. "We use our eyes to pick out relationships between things." Witness the tendency of people who are working on complicated projects to spread their papers out on a desk or tack them to a wall.

Conventional text displays usually ignore this quest for visual holism. Computers parsimoniously scroll out a page or less at a time, for example. To keep track of information on previous screens, people must rely on memory, a weak

COMPUTER IMAGES: DAVID SMALL

cousin to vision. Computers also tend to rob words of their context. You can search for a scene in Shakespeare, says Small, "but if you don't know where that scene falls in the play, and what's happening at that moment, and where that play fits in with the rest of Shakespeare's work, it's not going to be as useful to you."

World Wide Web sites are especially vexing in this regard, says Small. People often can't tell how the page they're on relates to others at the site, and have trouble gauging how much of the site remains to be viewed. One reason for this, according to Small, is that the Web erases any sense of a journey. "Suddenly your screen goes blank and something else comes up. There's no transition, no clear relationship between where you were and where you're going."

To Small, even books are a flawed medium. Although they provide a better indication of where you are in relation to the rest of the text, he says, "it is broken up into these one-page chunks. The page breaks themselves are not meaningful."

Accordingly, Small wants to confer on electronic text some of the advantages of handling a physical object but without the limitations of paper. Seeing the desired text in the distance and then traveling to it restores the journey that Small believes is lacking in computerized media. Once there, the reader can tilt the text by moving the stage—effectively peering up or down the length of the columns to judge their extent, or from side to side to glimpse other sections of the work receding into the distance. This helps provide some of the missing sense of context.

At the same time, because readers can easily visualize the structure of a work, Small says, they can glean significant information even from afar. The macro view of Shakespeare, with its uneven strands of text, "shows that the middle acts tend to have long scenes in them," says Small. "You'll hardly ever have a long scene in Act I." A slightly closer view reveals who is speaking and how much is said just by the color of the type

(which differs for each character in a play) and the length of the passage.

Similarly, the ability to see every occurrence of a particular word or a speaker helps readers pick out patterns in the text. Highlighting the word *begat* in the Bible, for example, lights up large clumps of verses in the Book of Genesis, hinting at the extensive genealogy to be found there. And Small plans to display two sets of Jewish holy books, the Talmud and the Torah, together, in an effort to "tease out the relationships between them." Readers will be able to highlight in the Torah the verses that are being commented on in the Talmud. "This will produce not just a pretty picture but a deeper understanding of the subject matter," Small predicts.

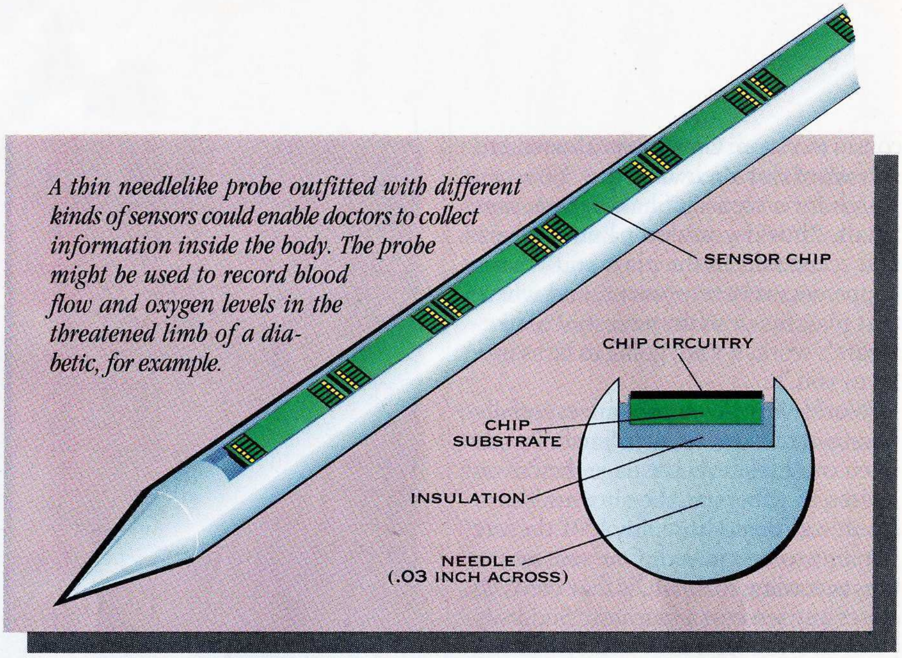
Of course, Talmudic scholars might balk at turning cranks on a toy stage and manipulating LEGO figurines of Moses or Ezekiel to find their way around. Lucky for them, the stage setup for Virtual Shakespeare is meant more as a playful expedient than as a practical controller. In his search for the perfect generic control device, Small has tried—and abandoned—a number of contraptions, including a LEGO helicopter outfitted with a virtual reality–type orientation sensor. Now he's concentrating on a simple set of force-sensitive levers instead. His aim is to provide more subtle and direct control than is possible with a mouse. "I want to make it seem as if you're holding the text in your hand," says Small.

Imagine, text you can hold in your hand. Perhaps, as the Bard wrote, "the wheel has come full circle."

—*DAVID BRITTAN*

More Bang for the Ouch

Doctors tracking the progress of a disease for research or treatment must often gather detailed information from inside the body. They may need, for example, to take the temperature of a malignant tumor at several spots or check the blood flow and oxygen levels in a diabetic's limb threatened with amputation.



A thin needlelike probe outfitted with different kinds of sensors could enable doctors to collect information inside the body. The probe might be used to record blood flow and oxygen levels in the threatened limb of a diabetic, for example.

One way of taking these measurements is with needlelike probes. Ideally, a single probe could collect several types of information, eliminating the need for multiple instruments and, for the patient, multiple pinpricks. While only single-purpose devices have been available, a needle that has been under development by MIT researchers could someday fit the bill.

Led by Kenneth S. Szajda, a research affiliate in the Harvard-MIT Division of Health Sciences and Technology, the MIT team has been developing a prototype device over the last six years. The designers—including H. Frederick Bowman, who heads the MIT Cancer Hyperthermia Program and is a lecturer in radiation therapy at Harvard Medical School, and Charles G. Sodini, a professor of electrical engineering and computer science at MIT—have so far outfitted their instrument only with multiple temperature sensors, the first kind of sensor they have created. But the probe should be able to handle different kinds of measurements at the same time because it can work with any sensor that fits its electronic specifications.

Along the length of the probe runs a thread-sized groove in which eight microchips lie tightly packed. Each chip in the prototype both senses the temperature at its location and processes the information into a form a computer can read and analyze. A ninth chip near the end of the needle opposite the tip coordinates the information flow to a personal computer, which is linked to the probe by a flexible cable.

According to Szajda, the linkage between sensor and processing electronics in each chip practically eliminates electrical noise that could otherwise corrupt sensors' signals. And the probe's diameter is 30 percent smaller than that of conventional probes, which translates into less pain for patients.

Monitoring Cancer Treatment

Szajda came up with the idea of an electronic, multipurpose medical probe while doing undergraduate and graduate research with Bowman. The original idea was to create a tool to monitor a cancer treatment that uses heat to boost the effectiveness of radiation and chemotherapy. In this therapy, as heat is applied, blood rushes to the tissue to cool it down. The rush of blood brings additional oxygen, which is thought to enhance the anticancer action of the toxic agents. To understand how best to take advantage of these effects, researchers need information concerning several questions, Bowman explains. The probe could provide the answers.

For instance, he says, "For any given temperature rise, how much will the

DIAGRAM: DEBORAH PERUGI

blood flow increase? How long will that increase in blood flow persist after you're no longer heating?" A tool that measures both blood flow and temperature at the same time could tell clinicians whether blood flow—and therefore oxygen level—remains elevated long enough to allow them to, say, do the heating in one room, then move the patient to another room for radiation treatment.

Bowman sees a host of other medical uses for the multipurpose needle as well. Organ transplants, for example, sometimes fail because blood vessels are not properly reconnected or the connection becomes blocked, cutting off the flow of blood to the new organ. A device that tracks blood flow could help transplant teams correct any such problem. In this case, the probe's advantage is not its potential use with different sensors but with multiple sensors of one kind. The more sensors on the device, the more accurate the picture of blood flow to the organ.

Hoping to privately commercialize some of his work, Szajda is now independently designing electronic oxygen and radiation sensors for his probe, as well as evaluating the development of a blood-flow sensor. The challenges involved with these tasks are mostly mechanical, focusing, he says, on "how to build the structure you need and at the same time not disrupt the circuitry."

An instrument that can measure both oxygen levels and blood flow might help diagnose conditions such as angina—severe chest pain that occurs when the heart is starved for oxygen because of insufficient blood flow. And in connection with cancer treatment, a probe including a radiation sensor would let researchers measure how much radiation is delivered to a tumor at a given time, as well as the total amount of radiation received. No technique is "available right now to make a direct measurement of that sort," says David Gladstone, chief of clinical physics in radiation oncology at Dartmouth Hitchcock Medical Center in Hanover, N.H. Moreover, if a dose of radiation failed to kill as many tumor cells as expected, a multisensor probe could help researchers understand whether inadequate blood flow or oxygen supply were to blame. Then doctors could manipulate blood flow and oxygen levels before delivering further doses of radiation. Szajda's probe, says Gladstone, would determine what's happening inside a tumor in a way that nothing does today. —NANCY ROSS-FLANIGAN

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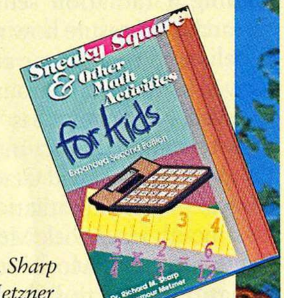

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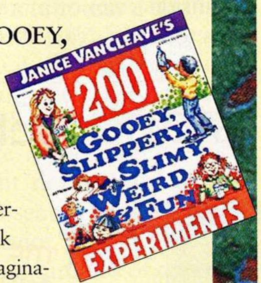

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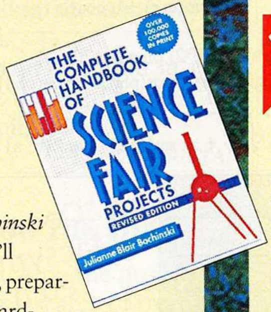

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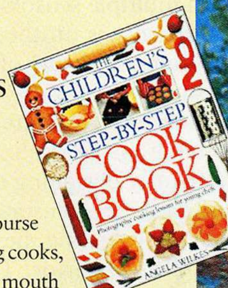

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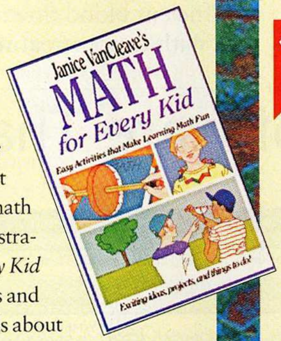

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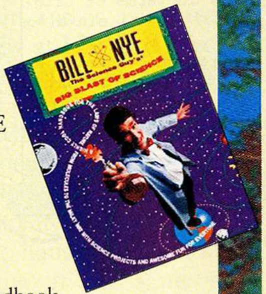

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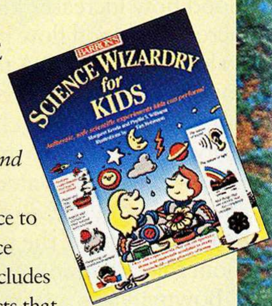

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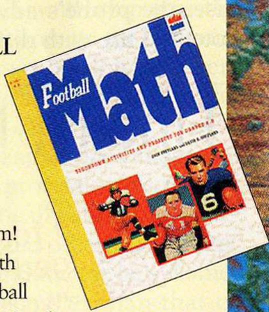

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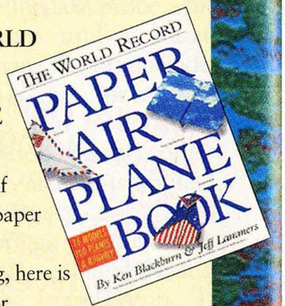

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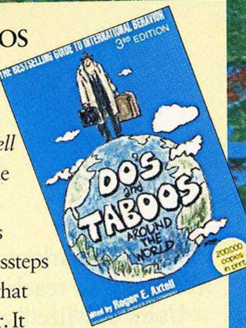

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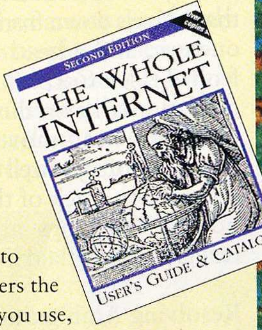

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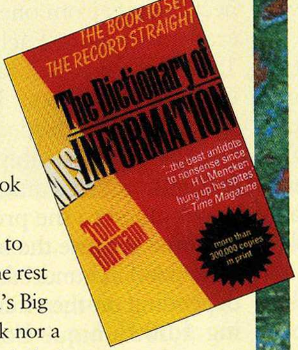

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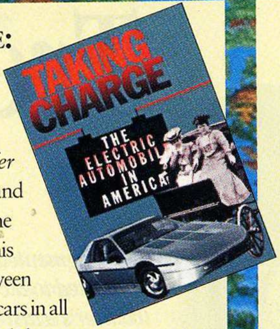

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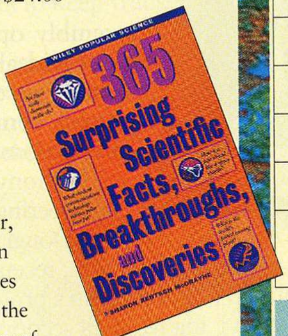

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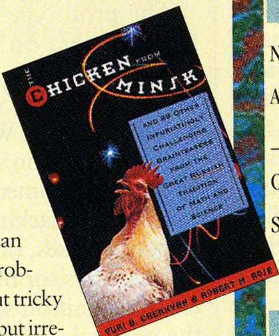

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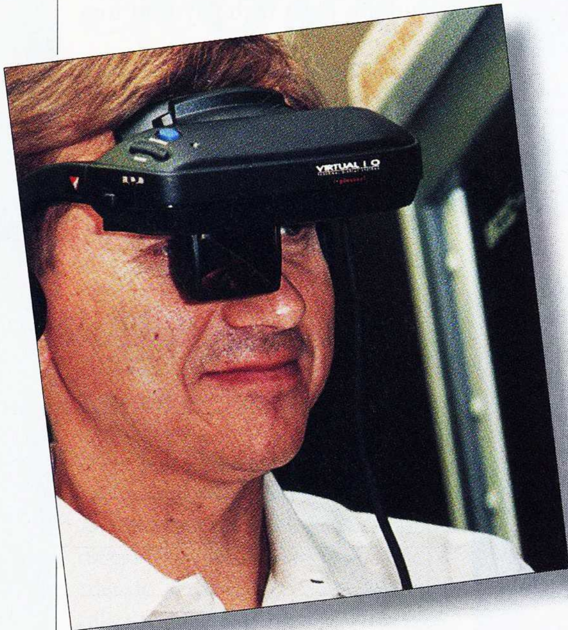
Trends



This "augmented-reality" headset—connected to a computer worn around the user's waist—enables an assembly worker to see instructions superimposed over a workpiece, eliminating the need for cumbersome manuals.

Virtual Assembly

"Some assembly required." This phrase strikes fear into the heart of every parent faced with putting together a bicycle on the eve of a kid's birthday. But it's also an intimidating fact of life for manufacturing firms—perhaps none more so than aircraft makers, whose employees must often piece together bewildering assortments of parts using volumes of jumbled instructional verbiage. Wouldn't it be nice if these complex transportation systems could tell an assembler how to put them together?

For some airplane-factory workers, certain plane parts can do just that, with the aid of augmented reality (AR). This technology melds virtual-reality viewers or other visual displays with positional trackers and ever smaller and faster computers to provide real-time assembly instruction. Unlike virtual reality, in which the user is completely immersed in an artificial world, AR lets you see the real world as well as an additional overlay of information that appears attached to the workpiece itself.

Seeing instructions and diagrams superimposed onto a workpiece beats "lining things up by sight, measuring, or trying to figure out what to do from a blueprint," says Ulrich Neumann, a professor of computer science at the University of Southern California, who designs augmented-reality units for use in assembly operations. The technique is ideal, he says, for any jobs that are so complex that the operator is continually looking for instructions.

Anthony Majoros, a senior engineering scientist at McDonnell Douglas Aerospace in Long Beach, Calif., recently began testing one of Neumann's prototype systems. Pointing to small sections of the fuselage of a DC-10 aircraft, he explains that the AR device can aid assembly workers by highlighting intended drilling locations or displaying explanations of where and how a particular sealant should be applied.

The prototype system consists of a video camera on a tripod that is connected to a Silicon Graphics workstation with a flat-panel color monitor, all on a roll-around cart. When a worker wheels the cart to certain sections of the aircraft and aims the camera, the computer looks for fiducial markings—pre-placed dots, targets, crosses, or natural features like holes, seams, or bumps—and uses pattern-recognition software to determine the particular unit under construction and establish the correct spatial relationship between the camera and the object. The computer then calls up the appropriate graphics and instructions, which have been preprogrammed into the system, and superimposes them in the proper orientation over the assembly on the computer screen. Once an assembly step is accomplished, the operator triggers the next procedure using a keypad.

Farther up the coast in Bellevue, Wash., aircraft maker Boeing is also exploring the potential of augmented reality but with more portable, "wearable" systems. Boeing project manager David Mizell believes that these "garments" would be perfect for a number of complex manufacturing and assembly jobs, particularly those that require two free hands to reach inaccessible places.

Users of Mizell's system wear a modular, 2.75-pound Honeywell computer around the waist like a skin diver wears a weight belt. They also don a see-through visor from Digital Vision Corp. that swivels down from a headband over one eye, and a head-mounted camera from TriSen Corp. that looks for fiducial landmarks on the assembly. When the user's head moves side to side or back and forth, Mizell explains, the computer keeps track of the position of the fiducial markings and automatically realigns the overlaid information.

Resolving Ambiguities

Boeing's first application of the technology has been in its "wire shop," where workers assemble wire bundles that connect circuits from one section of an aircraft to another. Each plane has about 1,000 such bundles, each of which must be preassembled on 3-by-8-foot pressboard sheets studded with pegs. The conventional assembly technique, which relies on myriad markings on plotter paper glued to the pressboard, is cumbersome because the bundles have to be assembled in hundreds of different ways depending on the aircraft model. "Storing 1,000 unique boards for bundles requires a lot of space," says Mizell, "and many are changed for individual customers." With AR, wiring configurations for all models are stored in the computer. When the aircraft model is called up, the computer displays how the bundles should be assembled one wire at a time using guide lines that appear over the blank board. This eliminates ambiguity and improves efficiency, he says. Moreover, any board can now be used for any bundle.

As promising as the results have been so far, researchers caution that the technology has been tested only under carefully controlled conditions and is not yet ready for prime time. The main limitation, says Neumann, is with tracking. The system often has difficulty repositioning the overlaid information in

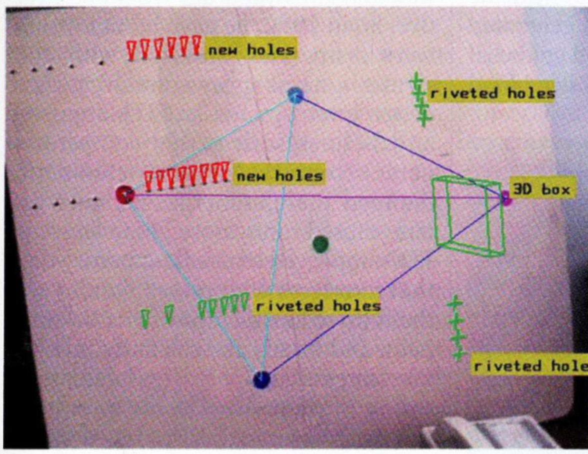
PHOTO: HONEYWELL

exactly the right spot over the workpiece when the camera's view is distorted by bad lighting or occluded, he explains. For example, if an operator blocks the camera lens with a wrench while tightening a bolt, the onscreen overlay could drift as the operator's head turns. "It isn't very helpful if an arrow is suddenly pointing to the wrong place," he says.

Neumann says the consensus is that hybrid trackers, units that have two or more different tracking technologies built in, will be required to solve the problem. One system, which is being tested in combination with the video pattern-recognition approach used by McDonnell Douglas and Boeing, is called magnetic tracking. This technique relies on an electrical device containing huge magnetic coils that generate three magnetic fields aligned at right angles to one another in the space surrounding the work area. A sensor in the AR helmet measures the relative strength of each field to divine the camera's precise orientation with respect to the workpiece.

Eric Foxlin, chairman and vice-president of research and development at InterSense Corp. in Cambridge, Mass., is developing prototypes of an "acoustic inertial" hybrid tracker for a range of potential AR tasks, including Boeing's "wire shop" application. In one such unit, three ultrasonic speakers placed at right angles to each other on the helmet send out ultrasonic chirps or pulses to microphones placed around the work area. By measuring the time it takes for the pulses to reach the microphones, the computer can calculate how far the headset is from each one and determine its precise location and orientation. The tracking unit also uses gyroscopes and accelerometers to measure the worker's head movements to help keep track of the camera's position.

Any technique, by itself, has limitations, says Foxlin. Metal objects can distort magnetic fields, any solid object can distort ultrasonic signals, and slightly inaccurate readings from the gyroscopes and accelerometers can accumulate rapidly and cause drift. But with two systems providing continual updates, he says, one can compensate when the other fails.



Through a camera in the user's headset, the computer looks for fiducial markings—in this case, painted dots on a metal panel—to determine precisely where to overlay instructions for drilling and riveting.

As more prototype experiments prove the concept and developers home in on remedies to technical shortcomings, interest in AR appears to be growing. The early work, though limited, says Neumann, "has brought more people and different technologies to the field." In anticipation, AR developers such as Honeywell are now targeting a wide range of tasks beyond assembly and manufacturing, including maintenance, construction, military, and even medical and surgical applications.

—LARRY KRUMENAKER

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Taking On the Common Cold

Colds researchers deleted the word "cure" from their lexicons in the early 1960s when they discovered that some 200 different viruses can cause colds—far too many to conquer with a vaccine, the conventional method of defeating an infectious disease. With the discovery of each new family of cold virus—rhinovirus, coronavirus, Coxsackie virus, adenovirus, respiratory syncytial virus, to name a few—researchers sank into a deeper funk. And as funding for common-cold research by the National Institutes of Health dwindled to its current level of $2 million per year, a mere 0.02 percent of its total budget, most researchers moved on to study influenza, herpes, AIDS, or other viral diseases.

But after years of low-profile research, biologists who remained dedicated to fighting the common cold believe they have homed in on a strategy both to stop cold viruses from replicating and to dampen the immune response that produces symptoms—together, the closest thing yet to a cure.

This optimistic scenario evolved in parallel with the gradual scientific unraveling of how the immune system reacts—or, more precisely, overreacts—when it encounters a cold virus. In fact, although cold viruses infect only about 1 percent of the epithelial cells that line the nasal passages (a mere pinprick compared with most other infectious viruses), they induce the immune system to launch a full-fledged attack that can result in the all-too-familiar congestion, runny nose, aches, and pains.

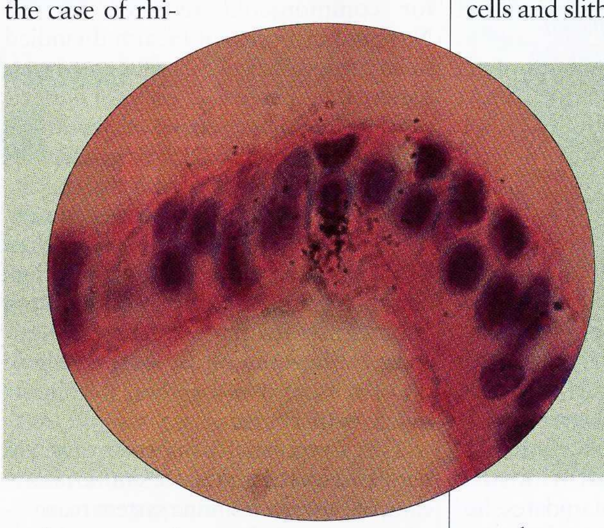
No one is sure why the immune system reacts so vigorously or why the resulting symptoms make us feel so lousy. But research shows that this aggressive response is present in vertebrates and invertebrates, suggesting that as humans evolved, the benefits of overkill outweighed the disadvantages.

In any case, viewing the immune system as part of the problem, rather than

DIAGRAM: ULRICH NEUMANN, YOUNGKWAN CHO, ANTHONY MAJOROS

blaming only the viruses, is "the start of something new," says Jack M. Gwaltney, Jr., a professor of medicine at the University of Virginia School of Medicine who has pioneered treatments aimed at shutting down the body's runaway reaction to cold viruses. An important clue led Gwaltney and his colleagues to this novel theory: the knowledge that even though many different viruses cause colds, the body's reaction is almost the same for each one.

This response begins after virus-laden droplets, often from someone else's sneeze or cough, come in contact with nasal epithelial cells. In the case of rhinoviruses, a strain that causes most colds, the virus attaches to a receptor that coats the surface of the cells. This receptor, called intercellular adhesion molecule-1, or ICAM-1, is as slippery as silk to most of the natural world but is like Velcro to a rhinovirus.



Because the immune system launches a full-blown attack against relatively harmless colds—even when a virus (black dots) infects only 1 percent of nasal cells (red ovals)—researchers think dampening the immune response may be the key to a cure.

Once the virus invades the nasal cells, the cholinergic nervous system—an early line of defense, so named because its signals are transmitted by a neurotransmitter molecule called acetylcholine—responds by triggering the secretion of a thin watery fluid through the mucous membranes to try to flush out the virus. When this happens, most people immediately sense they are coming down with something.

A molecular biologist would need a couple of hours, a large blackboard, and several colors of chalk to diagram what happens next as cells infected by the virus tap into the body's equivalent of the Internet—a complex set of immune reactions, some of which help repel or destroy the virus, but which also may make people miserable.

First, the epithelial cells release histamine, a protein hormone (or cytokine) that dilates nearby blood vessels and floods the region with fluid, exacerbating an already runny nose. At the same time, infection-fighting white blood cells that are pulsing along arteries near the infection recognize a beacon generated by cytokines from the stressed epithelial cells and slither out of the swollen blood vessels to reach the infected tissue.

Once they arrive, the white cells release cytokines of their own, including interferon-alpha2, which signals nearby cells to make enzymes that interfere with viral replication. They also signal the infected tissue to release prostaglandin, a hormonelike compound that increases dilation of nearby blood vessels, raises body temperature to slow virus replication, and initiates the production of neutralizing antibodies. A physician would call the end result "inflammation" since the affected nasal tissue appears reddened, warm, swollen, and tender, but most people would just call it a bad cold.

Gwaltney and others hoped that colds might be cured when interferons were discovered. But human trials proved that these antiviral cytokines did virtually nothing to reduce cold symptoms. Unfortunately, traditional anti-inflammatory drug treatments alone didn't work either. As Gwaltney explains, it's still essential to deplete the virus, not because it is so dangerous—it isn't—but because it will prolong the powerful immune response, much like the burr under the saddle of a horse will make a horse keep bucking uncontrollably.

Gwaltney wondered what would happen if a combination of anti-inflammatory and antiviral drugs would be effective. So in 1992, he gave human volunteers deliberately infected with cold viruses a nasal spray containing three drugs: Ipratropium, an FDA-approved anticholinergic drug that competes at nerve receptors with acetylcholine (to dampen the cholinergic nervous system–caused runny nose); Naproxen, an FDA-approved anti-inflammatory drug that interferes with prostaglandin synthesis (to reduce dilation of blood vessels, pain, and fever); and the antiviral cytokine, interferon-alpha2b (to inhibit replication of rhinoviruses). He found that the drug combination reduced symptoms from rhinovirus infections but was ineffective against other cold viruses.

Gwaltney, who has a patent on the drug therapy, hopes that it will reduce symptoms in the 50 percent of colds caused by rhinoviruses. He is currently seeking a pharmaceutical company to package and sell his treatment.

In the search for agents that would be effective against all cold viruses, researchers have since discovered other cytokines in the fluid of tissue infected with cold viruses. Ronald Turner, director of the Division of Pediatric Infectious Diseases and Clinical Immunology at the Medical University of South Carolina, says that one of these, interleukin-8 (IL-8), is found in virtually all cold patients' nasal fluids, while cytokines that are involved in other kinds of infections are present only some of the time.

That evidence has led him and others to propose that an effective IL-8 blocker, if one could be developed, might short-circuit the inflammatory process in all

PHOTO: JACK M. GWALTNEY, JR.

colds. In fact, the pursuit of safe and effective cytokine blockers, including an IL-8 blocker, is now one of the hottest areas of research in a number of pharmaceutical companies—not only for the treatment of viral diseases but also often fatal bacterial infections.

Antiviral Agents

Researchers at Agouron Pharmaceuticals in La Jolla, Calif., claim to have discovered other compounds that attack cold viruses, including one that inhibits 3C protease, an enzyme essential for rhinovirus replication. The enzyme, which is shaped like a doughnut, slips down the long viral protein and cuts the strand in just the right places prior to replication. Agouron is developing chemicals that it says can plug the doughnut hole and immobilize the enzyme.

On another front, Bayer Corp. is testing a spray that keeps rhinoviruses from attaching to the ICAM-1 receptors on nasal epithelial cells. The spray, which contains soluble ICAM-1, has reduced the occurrence of colds in chimpanzees. The company plans to test the spray on human volunteers who will be given the spray a few times a day during the cold season to determine if it will reduce their incidence of colds.

If such antiviral compounds prove successful, they could be used prophylactically to prevent a cold from occurring in the first place, thus obviating the need for anti-inflammatory drugs. But according to David Proud, a biochemist and professor of medicine at Johns Hopkins who is also engaged in colds research, such a product might not find much of a market unless it is accompanied by an anti-inflammatory agent. "Obviously, you'd like to block cold viruses as early as you can in the pathway," he says. "But the fact is that most patients won't be willing to spend money until they get infected."

—*Rex Graham*

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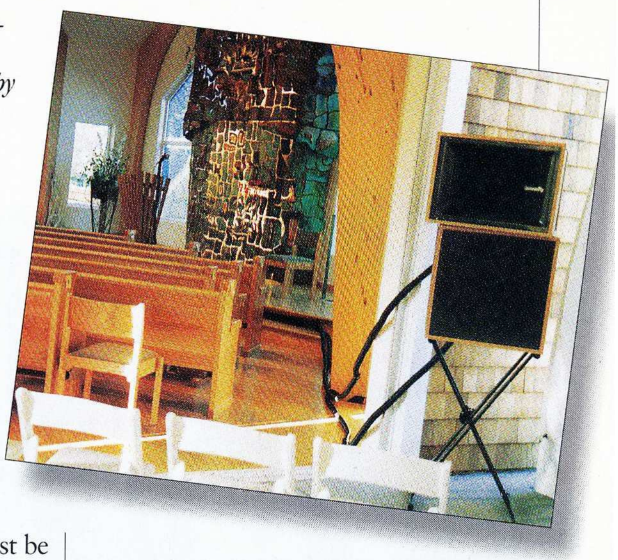
A kosher public-address system, powered by compressed air rather than electricity—whose use is forbidden by Jewish law—proved effective at the Hampton Synagogue on Long Island.



Kosher Sound

Almost everyone knows there are kosher hot dogs and pickles, but you have to be a real aficionado of kosher to know that there also is such a thing as a kosher sound system. Seeing a niche market, a small Washington, D.C.–area research company last year received a patent for just such a system. And in what must be a textbook example of how a new technology can be transformed into other products, the company is developing a listening device based on the same principles that would allow farmers to hear insect larvae munching away inside grain elevators.

Both applications evolved out of the same core problem: How do you make a sound system without electricity? For Orthodox Jews, the question arises in connection with the Biblical commandment not to do work on the Sabbath or other holy days. Traditionally, one definition of forbidden work was lighting a fire. In the modern age, orthodox rabbis have taken the modern incarnation of fire to be electricity, and therefore any effort on their congregants' behalf that initiates the flow of electricity is forbidden. In practice, this means that on the Sabbath, Orthodox Jews are not allowed to turn on a light or push a floor button in an elevator. The prohibition also rules out the use of electrically driven microphones.

This observance exacts a price. The farther back that members of a congregation are seated in a synagogue, the harder it is for them to hear. Moreover, rabbis and cantors must regularly strain their voices in their efforts to be heard by all worshippers. This problem is exacerbated when they are praying or singing facing the altar with their backs to the congregation and on the High Holy Days of Rosh Hashanah and Yom Kippur when the services are so crowded that people often must be seated outside the main sanctuary. "Our cantor says that he would rather sing four operas than one Yom Kippur service," says Marc Schneier, a rabbi with the Hampton Synagogue in Westhampton Beach, Long Island.

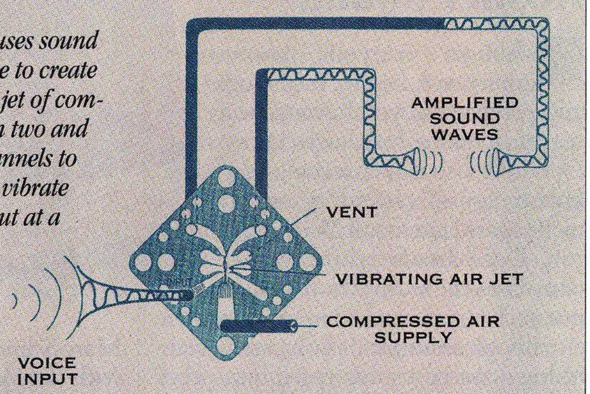
It was into this quandary that Defense Research Technologies (DRT) of Rockville, Md., has stepped with a nonelectrical sound-amplification system. The technology was first developed by DRT president Tadeusz Drzewiecki and others at the U.S. Army's Harry Diamond Laboratories in the late 1960s and early 1970s, when they, too, faced a problem with sound and electricity. Crew members on the decks of noisy aircraft carriers wanted a way of talking to each other, but they were afraid that sparks from traditional electric microphones would ignite the jet-fuel fumes that waft across the deck surfaces.

In response, the Army researchers came up with the principles for a system that Drzewiecki has patented as an "acousto-fluidic" technology. The system works on the principle that sound can travel farther if it is wind-born. In fact, some rabbis have dubbed the new technology a "wind microphone."

Drzewiecki says the system works by "taking advantage of the mechanical gain obtained by the deflection of a high-energy jet of air." As a person speaks into an input horn, the pressure waves generated by the voice hit a smooth jet of air released from a canister of compressed air and cause it to vibrate.

The wavering jet stream is then split by a thin piece of laminated plastic into two channels, one carrying the upper range of the sound waves and the other carrying the lower range. The split sound waves are then routed through separate tubes so they will bang from

PHOTO: TADEUSZ DRZEWIECKI



The novel kosher amplifier uses sound waves from a speaker's voice to create vibrations in a fast-moving jet of compressed air. The jet is split in two and routed through separate channels to hit a faster jet, causing it to vibrate just like the original voice but at a higher amplitude. The process can be repeated several times before the amplified sound is routed through tubes to output horns.

opposite sides into another, faster-moving jet of compressed air. As waves from one channel push on the jet stream with positive pressure, waves from the other channel, which are completely out of phase, pull on it from the other side with negative pressure, increasing the amplification effect.

The split jets of air, which travel with much more force than a voice, cause the smooth jet they come in contact with to vibrate at the same frequency but with higher amplitude. This phenomenon can add enough kinetic energy to the pressure wave to raise its volume tenfold. The amplified sound, imprinted with the original voice harmonic, travels along plastic piping and emerges from speaker horns at the ends of the tubes.

The army engineers were able to demonstrate that the principle worked—but were not able to get the sound loud enough to be heard on flight decks where the cacophony frequently reached 120 decibels. Part of the problem was that they did not realize they could theoretically repeat the steps of the process indefinitely to achieve the desired volume. Static in the line—an issue that Drzewiecki later resolved by making the flow of pressurized air less turbulent—also stalled development.

Instead, Drzewiecki built a model of the technology, which he implemented as a temporary intercom system in his office building. Then in the late 1970s, a rabbi walking down the halls saw the system with its air bottles and lack of electrical connections and realized that it could be used in a synagogue.

After discussing the idea with the rabbi, Drzewiecki sought kosher status for the acousto-fluidic technology by petitioning the Rabbinical Council of America, a governing body for North America's 1,000 Orthodox Jewish congregations. Fifteen years later, the system was formally declared kosher because the amplification process, according to the rabbis' interpretation of the Halacha (Jewish law), was deemed not to be "work." Moreover, the use of the valve that released the jet of air from a tank of compressed air was not considered a violation because the valve could be automatically programmed to be turned on and off before the Sabbath and holy days. The decision was confirmed by the Institute of Science and the Halacha, an organization in Jerusalem devoted to finding solutions to difficulties created by orthodox observance. While 15 years might seem a long time if one were seeking, say, a patent, Drzewiecki was informed by the rabbis that it was unusual for deliberations on such a matter to be concluded in so short a period.

In 1994, Drzewiecki mounted a demonstration at Rabbi Schneier's synagogue during crowded Rosh Hashanah and Yom Kippur services. He found that the volume 50 feet away was roughly the same as when the sound came out of the speaker's mouth—and people 100 feet away could also easily hear what was being said or sung. Schneier described the technology as "revolutionary."

The kosher sound system is currently too costly for many synagogues. Drzewiecki estimates that a system for a large 1,600-member congregation, for example, would cost about $20,000 because it would have to be custom designed and hand built. But he believes that if the units could be produced in quantity, the price could easily be halved.

There is also the aesthetic question of what a synagogue would look like with two long pieces of plastic piping stretching along its walls and onto the altar. The best solution, suggests Drzewiecki, would be for systems to be installed in newly constructed synagogues.

Listening for Larvae

Along with its attempts to break into the synagogue market, DRT is turning its attention and its technology to a completely different sound-amplification problem—bugs in the granary. Specifically, how does one detect the presence of weevil larvae in grains such as maize and rice before they hatch and destroy an entire stored crop? A traditional sound-amplification system might be able to register the larval eating sounds, which are generated at a level 10 times below that of human hearing. But electrical microphones could generate sparks that in turn could trigger an explosion in the grain dust, which is highly combustible.

Drzewiecki has begun work with the U.S. Department of Agriculture to see if a multi-stage acousto-fluidic system could detect the faint munching sounds. Grain samples would be put into tubes with cloth-covered holes in the sides. Small horns placed over the holes would feed the sounds into an air-driven amplifier, much like the one used in the synagogue sound system, except that it would amplify sound through a series of three interactions with smooth air jets. This solution not only reduces the risk of fire, Drzewiecki adds, but because Jewish law also prohibits the eating of insects, it also helps ensure that the grain is kosher.

—STEPHEN STRAUSS

DIAGRAM: DRT MANUFACTURING CO.

A Researcher's Conviction

The tragic nine-year odyssey of Petr Taborsky is best captured in the tale of two government-issued numbers glaringly at odds. First, there is federal patent 5,082,813, awarded to Taborsky, a bright young undergraduate at the University of South Florida, for inventing a way to make a reusable cleaner for sewage-treatment facilities. Then there is prisoner number 514527, issued by the North Florida penitentiary to Taborsky, a convicted felon who, for several months, was held in shackles on a chain gang.

Taborsky is surely not the first researcher to serve time; he may, however, be the first to be incarcerated for stealing his own research. His story caricatures the U.S. system of sponsored university research and intellectual property rights, featuring an overzealous university and a remarkably bullheaded young inventor.

Taborsky's tale begins in 1987 when, as a student at the Tampa-based University of South Florida, he took a job as a laboratory assistant. A nearby holding company, Florida Progress Corp., had paid USF $20,000 to conduct research on a claylike substance called clinoptilolite. The material, commonly used in cat litter, absorbs ammonium but becomes saturated relatively quickly. The company was hoping to find a bacteriological way to increase the amount of ammonium the clay could absorb so it might more affordably be used to filter the chemicals from wastewater in sewage-treatment plants.

As an undergraduate, Taborsky earned $8.50 per hour while working on the project in a civil engineering laboratory managed by Robert Carnahan, a dean for research at USF's College of Engineering whose long career had already earned him several patents. The project followed the standard arrangement between the university and the firm, or sponsoring agency: if any inventions or patents resulted from the research, the university would retain the patent but the firm would retain a preferential right to license the technology.

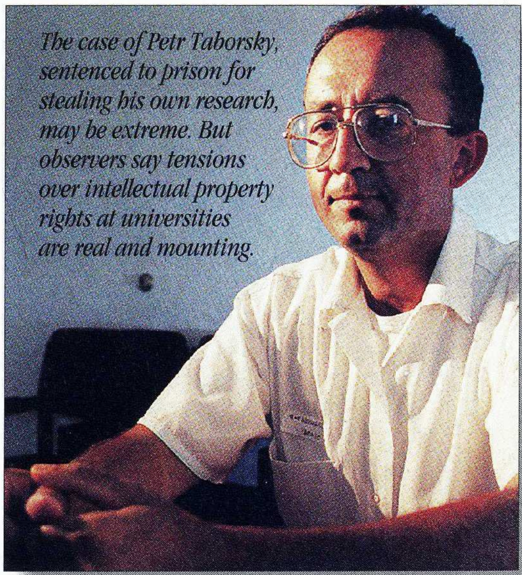
In what would become an important twist in this case, however, USF had not yet adopted a policy governing undergraduates' rights to their own research. In fact, all parties in this case now agree that Taborsky never signed a confidentiality agreement with the university delimiting his legal rights to the work he was engaged in. "Taborsky's case was something of an oversight; undergraduates simply aren't supposed to invent things," quips Leonard Minsky, director of the Washington-based National Coalition for Universities in the Public Interest, a Ralph Nader–affiliated nonprofit organization now aiding in Taborsky's legal defense.

Staking Claims

The hotly contested versions of Taborsky's case diverged in the latter half of 1988. Because Florida Progress had been hoping to find some kind of bacteria or enzyme to be used as an additive to the clay, the 26-year-old Taborsky, who was studying chemistry and biology, spent his summer trying to understand clinoptilolite's chemical properties. But when the three months of sponsored research on behalf of Florida Progress had ended, Taborsky says he received his professor's permission to pursue his own research, hoping he might use it as the basis for a master's thesis.

Spending many nights in the lab, often waking every 20 minutes to monitor his experiments, Taborsky had a breakthrough that summer. He found that when clinoptilolite was heated to a temperature of 850° F, its ability to absorb ammonium was significantly enhanced.

Taborsky knew he had found something both important and lucrative. The question was: who had a right to this intellectual property? The firm claimed, with some legitimacy, that the discovery grew out of its sponsored research. Taborsky's professor told him that the discovery belonged to the university because it had "shop rights" to any work undertaken at a campus lab. For his part, Taborsky believed that his work, undertaken largely on his own, was a novel departure that owed little debt to anyone. As Taborsky, now 34, tells it: "I decided I wasn't going to let them intimidate me."


The case of Petr Taborsky, sentenced to prison for stealing his own research, may be extreme. But observers say tensions over intellectual property rights at universities are real and mounting.

For a brief moment, a resolution of the dispute looked possible. After Taborsky's professor reported the discovery to representatives from the university and the sponsoring firm, a subsidiary of Florida Progress agreed to offer Taborsky a job and told him they would name him as the primary author on their patent application. Taborsky was tempted enough to sign a routine confidentiality agreement with the company—the first agreement he had signed. But the arrangement immediately fell through when Taborsky realized the contract offered him no real guarantee of employment, since it stated that the company could fire him at will. At this point, in the fall of 1988, Taborsky alarmed the parties involved by threatening to seek his own patent.

In a momentous turn of events, Taborsky, presumably intimidated and confused by the forces arrayed against him, left the school and his lab job, did

PHOTO: JOHN MORAN/NYT PICTURES

not take finals, and did not return to USF in any capacity. Weeks later, he was arrested and criminally charged with theft. A police report indicates that Carnahan, the project's principal investigator, told police Taborsky had taken two research notebooks from the university laboratory in violation of a confidentiality agreement. Taborsky admits that he took the notebooks, but he contends that they belonged to him. And, he rightly argued, he never signed any agreement with the university.

Taborsky maintains that USF pressed criminal charges initially to scare him into giving in. The university's actions only strengthened his resolve, but he has paid dearly for his obstinacy. Taborsky, a Czech citizen, saw his application for U.S. citizenship put on hold because of the case. His marriage crumbled. The university withheld his chemistry degree. In 1990, he was found guilty of grand theft and sentenced to 15 years of probation and 500 hours of public service.

Though he was forced to turn the material over to the university, he began applying for a patent. In Taborsky's view, his only hope for retaining his scientific integrity would come if the U.S. Patent Office, after reviewing the entire situation, would deem his work novel enough to merit a patent in his own name.

Despite the intervention of the university and of Carnahan, who claimed to be the invention's owner, the Patent Office held that Taborsky *was* the rightful inventor and awarded him a patent in 1992. But when university lawyers heard of the patent, they filed suit and successfully argued that Taborsky had violated his probation, which prohibited him from making further use of the research he had undertaken at USF.

Frustrated by Taborsky's recalcitrance, and terrified that the case might scare away would-be research sponsors, Francis Borkowski, then president of USF, successfully appealed for the judge in the case to sentence Taborsky to prison. Taborsky, still claiming that the patent was rightfully his, was sentenced to three and a half years. Following appeals, Taborsky began serving his sentence in January 1996 and has remained behind bars ever since, serving four months in a maximum-security state prison where he was shackled and required to work on a chain gang clearing trees and brush.

When media accounts last summer depicted a promising young scientist in leg irons, the governor's office stepped in to review the case. Dexter Douglass, legal counsel to Florida Governor Lawton Chiles, told the press that "we are concerned that the government overreached in this young man's case."

Clemency Rejected

But when Douglass tried to arrange a pardon, Taborsky refused, stating that "clemency will not undo my conviction. Petitioning for clemency is asking for forgiveness. My main concern is overturning my wrongful conviction."

Meanwhile, USF has remained steadfast. "The case is no different from that of a former student stealing something from the university, like precious books from the library," says Henry Lavendera, an attorney for the university. "We are concerned that potential sponsors will view it as a black eye for the institution if we allow student researchers to steal information."

USF president Betty Castor said in a recent statement that Taborsky has no one to blame but himself for his imprisonment. But in the future, Castor said, the university will file only civil suits for intellectual theft instead of pressing for criminal charges.

For the present, Taborsky will remain incarcerated, though now at a minimum-security prison after intervention from the governor's office. However, hearings on the outstanding civil suits in this case will resume this April. After having reportedly spent more than $300,000 in outside legal counsel to prosecute the case, USF recently succeeded in persuading a Florida judge to assign one of three patents to the university as restitution. It is now suing Taborsky over the remaining two patents. And Taborsky is countersuing the university, its board of regents, and two principal investigators personally, including Carnahan.

Leonard Minsky, whose organization is aiding in Taborsky's defense, considers the case a clear example of the negative effects that can result from corporate involvement in university research. The problem stems, he maintains, from a 1980 federal-policy change that gave universities the right to own patents on discoveries made on campus, and companies the right to obtain exclusive licenses by sponsoring the research. Since then, the financing of research by private industry on campuses has grown nationally to $1.5 billion per year, according to the National Science Foundation. And at USF, with 36,000 students the second-largest state university in Florida, sponsored research has grown from $22 million in 1986 to about $100 million today.

Offering some perspective on the matter, Cornelius Pings, president of the Association of American Universities, a Washington, D.C.–based consortium of the nation's largest research universities, notes that Taborsky's is the only case he has heard of where someone has been jailed over a patent dispute. But despite what he calls the "bizarre" nature of the case, Pings says that underlying tensions over intellectual property rights at universities are real and mounting.

"To the extent that patent income is there, there is no reason the university should give it away," Pings says. After all, he notes, "universities have profited handsomely from patent revenues for years and, for the most part, the system has been managed as it should be." But while today's universities cannot, and perhaps should not, maintain they are "above commerce," he says, they do need to protect their role "as temples of intellectual inquiry."

Pings says his association has "urged its member institutions to work out detailed rules governing intellectual property issues that are mutually acceptable to all parties." If they can't tackle these issues, universities stand to lose more than money, he says. "We could lose a lot of our credibility."

—SETH SHULMAN

BY RALPH C. MERKLE

It's a Small, Small, Small, Small World

With the tools of the nanotechnology trade becoming better defined, the ability to create new materials and devices by placing every atom and molecule in the right place is moving closer to reality.

THE PROPERTIES of materials depend on how their atoms are arranged. Rearrange the atoms in coal and you get diamonds. Rearrange the atoms in soil, water, and air, and you have grass. And since humans first made stone tools and flint knives, we have been manipulating atoms in great thundering statistical herds by casting, milling, grinding, and chipping materials. We rearrange the atoms in sand, for example, add a pinch of impurities, and we produce computer chips. We have gotten better and better at it, and can make more things at lower cost and with greater precision than ever before.

Even in our most precise work, we move atoms around in massive heaps and untidy piles—millions or billions of them at a time. Theoretical analyses make it clear, however, that we should be able to rearrange atoms and molecules one by one—with every atom in just the right place—much as we might arrange Lego blocks to create a model building or simple machine. This technology, often called nanotechnology or molecular manufacturing, will allow us to make most products lighter, stronger, smarter, cheaper, cleaner, and more precise.

The consequences would be great. We could, for starters, continue the revolution in computer hardware right down to molecular-sized switches and wires. The ability to build things molecule by molecule would also let us make a new class of structural materials that would be more than 50 times stronger than steel of the same weight: a Cadillac might weigh 100 pounds; a full-size sofa could be picked up with one hand. The ability to build molecule by molecule could also give us surgical instruments of such precision and deftness that they could operate on the cells and even molecules from which we are made.

The ability to make such products probably lies a few decades away. But theoretical and computational models provide assurances that the molecular manufacturing systems needed for the task are possible—that they do not violate existing physical law. These models also give us a feel for what a molecular manufacturing system might look like. This is an important foundation: after all, the basic idea of an electrical relay was known in the 1820s, and the concept of a mechanical computer that operated off a stored set of instructions—a program—was understood a few years later. But computers using relays were not built till much later because no good theoretical comprehension of "computation" existed. Today, scientists are devising numerous tools and techniques that will be needed to transform nanotechnology from computer models into reality. While most remain in the realm of theory, there appears to be no fundamental barrier to their development.

A Nano Tool Chest

Imagine putting some wires, transistors, and other electronic components into a bag, shaking it, and pulling out a radio—fully assembled and ready to work. Although this sounds fanciful, such remarkable "self-assembly" is, in essence, what chemists do whenever they synthesize materials. Mixing solutions in a beaker, a chemist lets the intrinsic attractions and repulsions of certain molecules and atoms take over. An art and science has evolved to arrange conditions so that atoms spontaneously assemble into particular molecular structures.

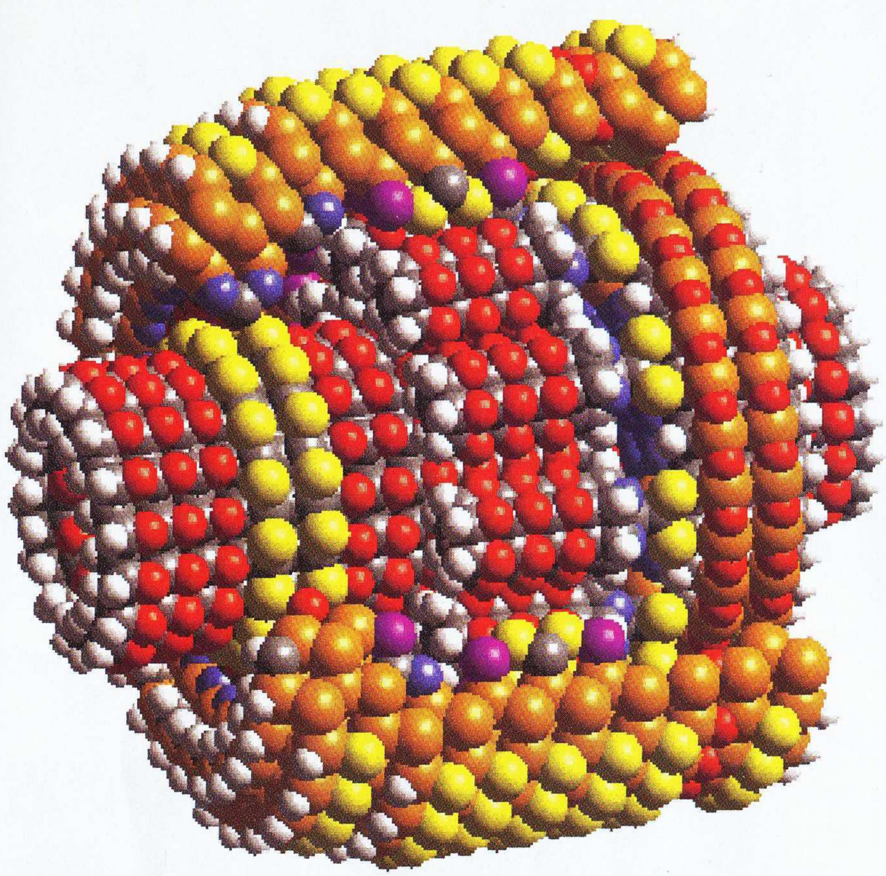
Similarly, we are surrounded and inspired by products that are marvelously complex and yet very inexpensive. Potatoes, for example, consist of tens of thousands of genes and proteins and intricate molecular machinery; yet we think nothing of eating this miracle of biology, mashed with a little butter. Potatoes, along with many other agricultural products, cost less than a dollar a pound. The key reason: if provided with a little soil, water, air, and sunlight, a potato can make more potatoes. Likewise, if we could make a general-purpose programmable manufacturing device that was able to make copies of itself—what nanotechnology researchers call an assembler—then the manufacturing costs for both the device and anything it made could be kept low.

A basic principle in self-assembly is selective "stickiness." If two molecular parts have complementary shapes and charge patterns—that is, one has a hollow where the other has a bump, or one has a positive charge where the other has a negative charge—then they will tend to stick together in a particular way to form a bigger part. This bigger part can combine in the same way with other parts so that a complex whole emerges from molecular pieces.

Self-assembly is not by itself sufficient, however, to make the wide range of products that nanotechnology promises. If the parts are indiscriminately sticky, for example, then stirring them together would yield messy blobs instead of precise molecular machines. We can solve this problem by holding the molecular parts in the proper position and orientation so that when they touch they will join together the way we want them to. At the macroscopic scale, the idea that we can hold parts in our hands and assemble them by properly positioning them with respect to each other goes back to prehistory: we celebrate ourselves as the tool-using species. But the idea of holding and positioning molecules is new and almost shocking. Nanoscale equivalents of "arms" and "hands" must be developed.

Current proposals for molecular-scale positional devices resemble normal-sized robotic devices, but they are about one ten-millionth as big. A molecular robotic arm could sweep systematically back and forth, adding and withdrawing atoms from a surface to build any structure that the computer instructed it to. Such an arm, composed of a few million atoms, might be 100 nanometers long and 30 nanometers

RALPH C. MERKLE is a research scientist at Xerox Palo Alto Research Center (PARC), where he is pursuing research in computational nanotechnology. He chaired the Fourth Foresight Conference on Molecular Nanotechnology, and will chair the next such conference, to be held in November. Before concentrating on nanotechnology, Merkle specialized in cryptography; he is the co-inventor of public key encryption.



The ability to pile atoms together in exactly the structure desired could lead to nanoscale mechanical devices such as this planetary gear, a commonly used device. In this computer model, white=hydrogen, red=oxygen, blue=nitrogen, yellow=sulfur, orange=silicon, gray=carbon, and purple=phosphorus.

around. Although it would have roughly 100 moving parts, it would use no lubricants—at this scale, a lubricant molecule is more like a piece of grit. Such ultraminiature tools should be able to position their tips to within a small fraction of an atomic diameter. Trillions of such devices would occupy little more than a few cubic millimeters (a speck slightly larger than a pinhead).

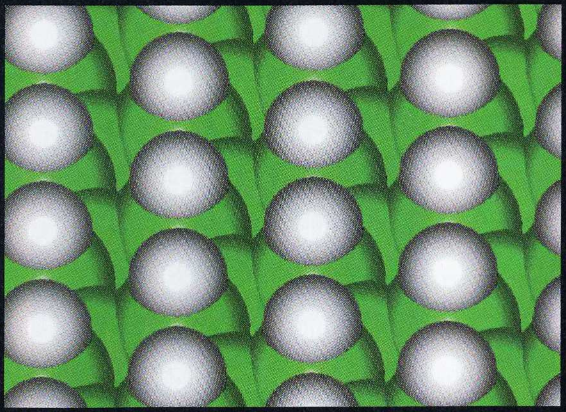
Molecular arms would be buffeted by something we don't worry about at the macroscopic scale: thermal noise. Atoms and molecules are in a constant state of wiggle and jiggle; the higher the temperature, the more vigorous the motion. To maintain its position, therefore, a nanoscale arm must be extremely stiff.

The stiffest material around is diamond. The strength and lightness of a material depends on the number and strength of the bonds that hold its atoms together, and on the lightness of the atoms. The element that best fits both criteria is carbon, which is lightweight and forms stronger bonds than any other atom. The carbon-carbon bond is especially strong; each carbon atom can bond to four neighboring atoms. In diamond, then, a dense network of strong bonds creates a strong, light, and stiff material. Indeed, just as we named the Stone Age, the Bronze Age, and the Steel Age after the materials that humans could make, we might call the new technological epoch we are entering the Diamond Age.

How can a diamond device of this scale be produced? One answer comes from looking at how we grow diamond today. In a process somewhat reminiscent of spray painting, we build up layer after layer of diamond by holding a surface in a cloud of reactive hydrogen atoms and hydrocarbon molecules. When these molecules bump into the surface they change it, either by adding, removing, or rearranging atoms. By carefully controlling the pressure, temperature, and the exact composition of the gas in this process, called chemical vapor deposition (CVD), we can create conditions that favor the growth of diamond on the surface.

But randomly bombarding a surface with reactive molecules does not offer fine control over the growth process; it is akin to trying to build a wristwatch using a sand blaster. We want the chemical reactions to occur at precisely the places on the surface that we specify. A second problem is how to make the diamond surface reactive at the particular spots where we want to add another atom or molecule. A diamond surface is normally covered with a layer of hydrogen atoms. Without this layer, the raw diamond surface would be highly reactive because it would be studded with the carbon atoms' unused (or "dangling") bonds. While hydrogenation prevents unwanted reactions, it also renders the entire surface inert, making it difficult to add carbon (or anything else) to it.

To overcome this problem, we could use a set of molecular-scale tools that would, in a series of steps, prepare the surface and create structures on the layer of diamond, atom by atom and molecule by molecule. The first step in the process would be to remove a hydrogen atom from a specific spot on the diamond surface, leaving behind a reactive dangling bond. This can be done with a "hydrogen abstraction tool"—a molecular structure that has a high chemical affinity for hydrogen at one end but is elsewhere inert. The tool's unreactive region serves as a kind of handle. The tool would be held by a molecular positional device, such as the molecu-



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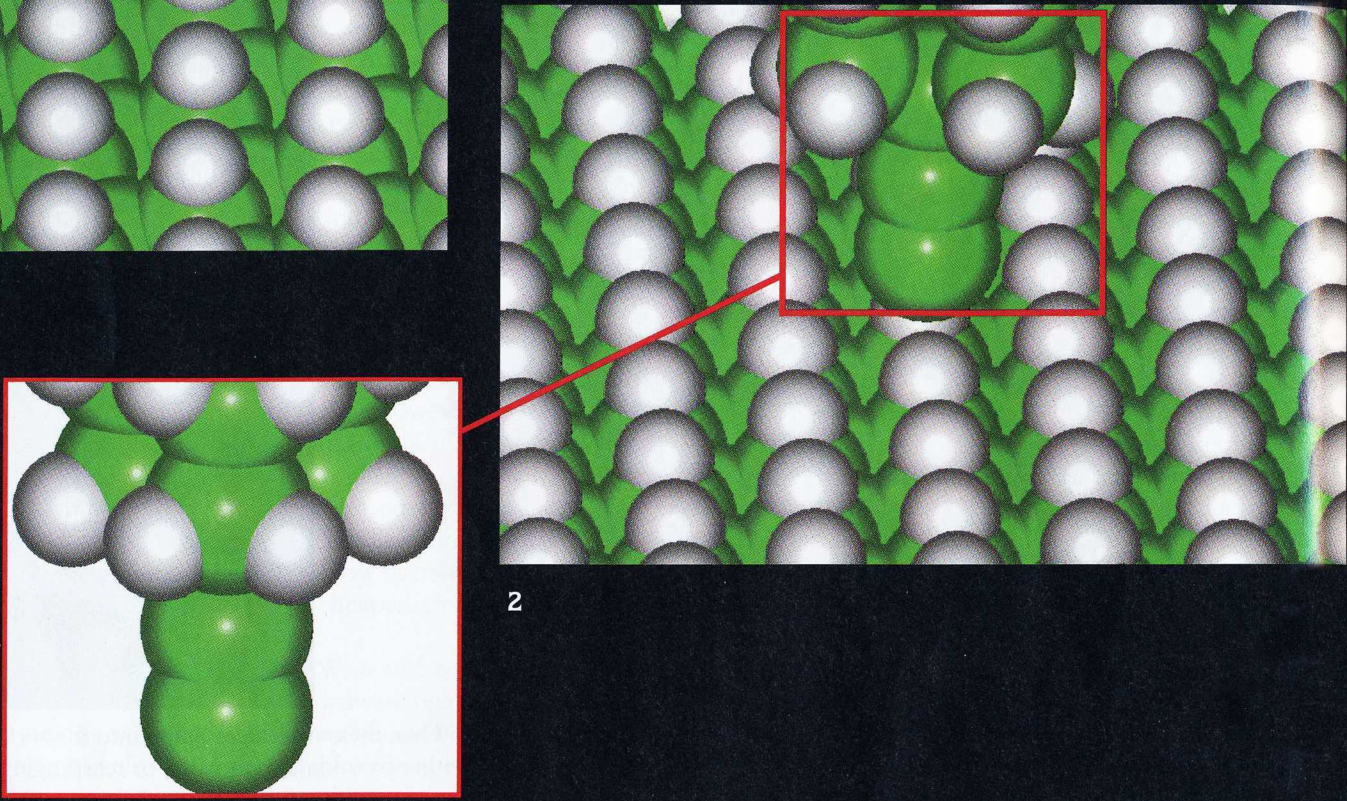

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lar robotic arm discussed earlier, and moved directly over particular hydrogen atoms on the surface we wish to abstract.

This creates a chicken-and-egg problem: we need a molecular robotic arm to build another molecular robotic arm. To solve this problem, we must at some point build a molecular robotic arm with something *other* than a molecular robotic arm. We could, for example, use a macroscopic positional device—such as an improved version of an existing atomic-force microscope—to make our first molecular robotic arm. Alternatively, we could self-assemble a simplified molecular positional device. These first crude positional devices could then be used to make better ones.

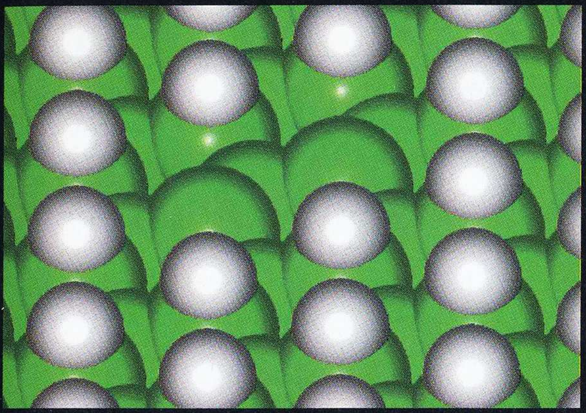
One suitable molecule for a hydrogen abstraction tool is the acetylene radical—two carbon atoms triple bonded together. One carbon would be the handle, and would link to a nanoscale positioning tool. The other carbon has a dangling bond where a hydrogen atom would be in ordinary acetylene. The environment around the tool would be inert (typical proposals involve the use of either vacuum or a noble gas, such as krypton or xenon).

Once this tool has created a reactive spot by selectively removing hydrogen atoms from the diamond surface, it becomes possible to deposit carbon atoms at the desired sites. In this way a diamond structure is built, molecule by molecule, according to plan. One proposal for this function is the dimer deposition tool. A dimer is a molecule consisting of two of the same atoms or molecules stuck together. In this case, the dimer would be C_2—two carbon atoms connected by a triple bond. In the deposition tool, each carbon in the dimer would be connected to a larger molecule by single bonds with oxygen atoms.

Trillions of molecular manufacturing tools would occupy a space slightly larger than a pinhead.

The hydrogen abstraction tool and dimer deposition tool would work together *(see illustration above)*. First, the abstraction tool would remove two adjacent hydrogen atoms from the diamond surface. The two dangling bonds would react with the ends of the carbon dimer. This reaction would break the carbon-oxygen bonds and then transfer the carbon dimer from the tool to the surface. Because the energy released during the reaction is much larger than thermal noise, the dimer will "snap" onto the surface and stay there.

A third proposed tool for making nanostructures is the carbene insertion tool. Carbenes—highly reactive carbon atoms with two dangling bonds—will react with (and add a carbon atom to)



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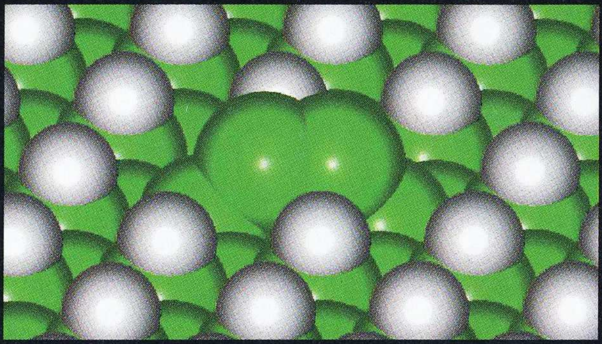

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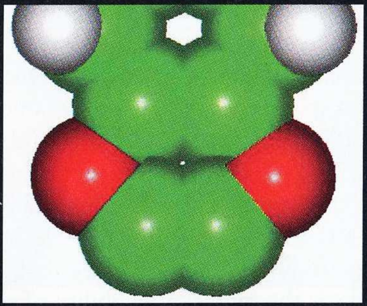

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The beginning of a nanostructure on a plain diamond surface. 1) The untouched surface, with carbon atoms shown as green and hydrogen as white. 2) A "hydrogen abstraction tool" (inset) with a highly reactive end is brought near the surface to pluck away a particular hydrogen atom. 3) The diamond surface after two adjacent hydrogens have been removed. 4) A "dimer depostion tool" carries two carbon atoms that are weakly connected to the oxygen atoms (red) of a larger molecule. 5) These two carbons break off and bond to the surface where the hydrogens were removed. All these tools would have to be held by precise positioning devices such as a nanoscale robot arm.

many molecular structures. Carbenes will readily insert into double or triple bonds, like the bond in the carbon-carbon dimer described above. A positionally controlled carbene could be attached almost anywhere on a growing molecular workpiece, leading to the construction of virtually any desired shape.

A fourth proposal is for a hydrogen deposition tool. Where the hydrogen abstraction tool is intended to make an inert structure reactive by creating a dangling bond, the hydrogen deposition tool would do the opposite: make a reactive structure inert by terminating dangling bonds. Such a tool would let us stabilize reactive surfaces and prevent the surface atoms from rearranging in unexpected and undesired ways. The key requirement for such a tool is that it include a weakly attached hydrogen atom. While many molecules fit that description, the bond between hydrogen and tin is especially weak; thus, a tin-based hydrogen deposition tool should be effective.

These four molecular tools should enable us to make a wide range of stiff structures—but only those that are composed of hydrogen and carbon. This is a much less ambitious goal than attempting to use all 100 or so elements in the periodic table. But in exchange for confining ourselves to this more limited class of structures, we make it much easier to analyze those that can be fabricated and the synthetic reactions needed to make them. In any case, this narrower proposal can be more readily and more thoroughly investigated than full nanotechnology. And diamond and its shatterproof variants fall within this category, as do the "fullerenes"—sheets of carbon atoms rolled into spheres, tubes, and other shapes. These materials can compose all the parts needed for basic mechanical devices such as struts, bearings, gears, and robotic arms.

Ultimately we'd like to add other elements—to create diamond electronic devices, for example, or add some nitrogen to the internal surface of a bearing in order to relieve strain (the carbon-nitrogen bond is longer than the carbon-carbon bond). Such structures, composed primarily of carbon and hydrogen in combination with nitrogen, oxygen, fluorine, silicon, phosphorous, sulfur, or chlorine, constitute what we call the class of "diamondoid" materials.

The Diamond Age

Natural diamond is expensive, we can't make it in the shapes we want, and it shatters. Nanotechnology will let us inexpensively make shatterproof diamond (with a structure that might resemble diamond fibers) in exactly the shapes we want. This would let us make a Boeing 747 that would weigh one fiftieth of today's versions without any sacrifice in strength. The benefit to space travel would also be dramatic. The strength-to-weight ratio and the cost of components are

> **Molecular-scale surgical tools injected into the bloodstream could heal at the cellular level the injuries that cause disease.**

critical to the performance and economy of space ships: nanotechnology could improve both of these parameters by about two orders of magnitude.

Nanotechnology could also radically alter the economics of energy production. The sun could provide orders of magnitude more power than people now use—and do so more cleanly and less expensively than fossil fuels and nuclear reactors—if only we could make low-cost solar cells and batteries. We already know how to make efficient solar cells: nanotechnology could cut their costs, finally making solar power economical. In this application we need not make new or technically superior devices; just by making inexpensively what we already know how to make expensively we would move solar power into the mainstream.

The manufacture of computer chips could undergo a profound change. There seem to be fundamental limits in how much further we can improve lithography, the process by which chips are now made. In lithography (literally, "stone writing"), we draw fine lines on a silicon wafer using methods borrowed from photography. A light-sensitive film—called a "resist"—is spread over the silicon wafer. The resist is exposed to a complex pattern of light and dark, like a negative in a camera, and developed. By repeating this process, an intricate set of interlocking patterns can be made that defines the complex logic elements of a computer chip.

But arranging atoms by throwing photons (or other particles) at a surface from a distance doesn't seem like the best approach, especially if we want to use three dimensions instead of just two; imagine building a car by throwing tools at it from more than a mile away. Thus if improvements to computer hardware are to continue at the current pace, in a decade or so we'll have to move beyond lithography to some new manufacturing technology. Designs for computer logic elements composed of fewer than 1,000 atoms have already been suggested—but each atom in such a small device has to be in exactly the right place. And spraying chemicals around simply can't arrange atoms with the needed precision.

Fortunately, diamond is an excellent electronic material. It outperforms silicon in several key respects. For one thing, electrons move faster in diamond than in silicon. Diamond can also work better than silicon at high temperatures. This is important because as chips get faster and faster, their performance is limited by the need to dissipate the heat that builds up in the circuitry.

Diamond has this advantage for two reasons. First, diamond has greater thermal conductivity than silicon, which lets heat move out of a diamond transistor more quickly. Second, diamond has a larger "bandgap" than silicon—5.5 electron volts, as opposed to 1.1 electron volts in silicon. The bandgap is the minimum amount of energy required to boost an electron from its relatively immobile state into the semiconductor's conduction band, where the electron moves freely under the influence of a voltage. As the temperature increases, more electrons gain the energy needed to jump into the conduction band. When too many electrons do this, the device changes from a semiconductor into a conductor; the transistor shorts out and stops working. Diamond's higher bandgap means it shorts out at a higher temperature.

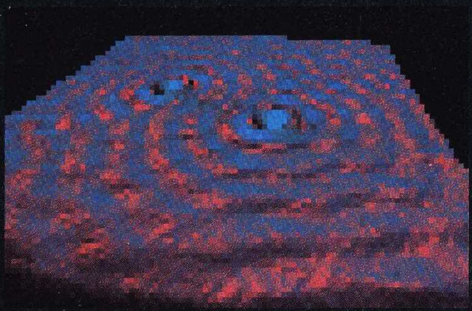
With nanotechnology, we should be able to build mass storage devices that can store more than 100 billion billion bytes in a volume the size of a sugar cube, and massively parallel computers of the same size that can deliver a billion billion instructions per second—a billion times more than today's desktop computers.

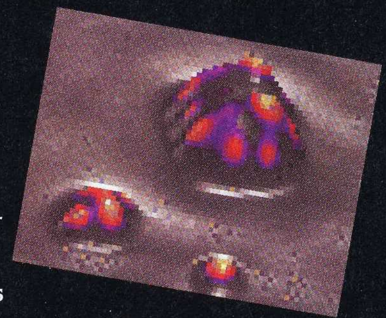
The availability of nanoscale devices could radically redefine surgery, too. There is today a fundamental mismatch between what's needed to treat injuries and the capabilities of our tools. The cellular and molecular machinery in our tissue is small and precise, yet today's scalpels are, as seen by a cell, crude scythes that rip through tissue, leaving dead and maimed cells in their wake. The only reason that modern surgery works is the remarkable ability of cells to regroup, bury their dead, and heal over the wound.

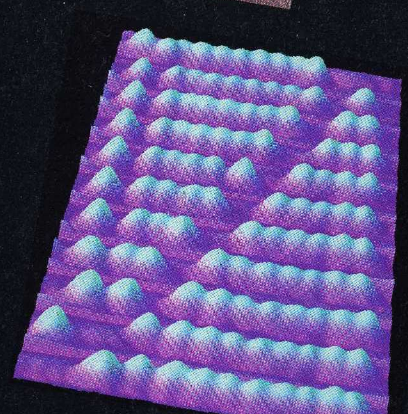
Surgical tools that are molecular in both size and precision should let us directly heal, at the molecular and cellular level, the injuries that cause disease. A molecular robotic arm less than 100 nanometers long, for example, would easily fit into the circulatory system (a single red blood cell is about 8,000 nanometers in diameter) and would even be able to squeeze inside individual cells.

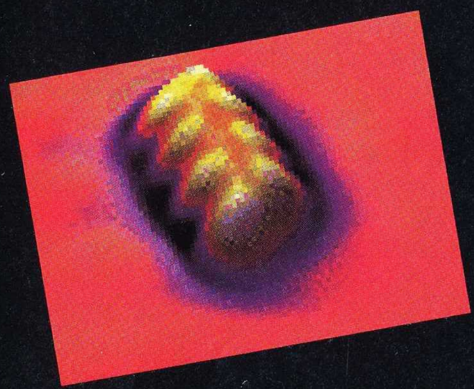
One application would be in cancer therapy. We could design a small device able to identify and kill cancer cells. The device, which would incorporate a nanoscale computer and several binding sites that are shaped to fit specific molecules, would circulate freely throughout the body, periodically sampling its environment by determining whether its binding sites were occupied. The more frequently a site was occupied, the higher the concentration of the molecule for which that site was designed. A nanodevice with a dozen different types of binding sites could in this way monitor the concentrations of a dozen different types of molecules that occur normally in the body but whose concentrations relative to one another change when cancer is present. The computer could determine if the profile of concentrations fit a preprogrammed profile and would, when a cancerous profile was encountered, release a poison that selectively kills the cancer cells.

Each device could incorporate a nanoscale pressure sensor that would allow the cancer killer to receive instructions through ultrasonic signals in the megahertz range. By "listening" to several macroscopic acoustic signal sources, the device could determine its location within the body much as a radio receiver on earth can use the transmissions from several satellites to determine its position. Awareness of its own location within the body would help the device decide whether it was









Although too slow for practical molecular manufacturing, a scanning probe microscope (SPM) can position atoms precisely. It can also produce images of individual atoms. Clockwise from top left: Two defects, possibly impurity atoms, adorn a copper surface; crystal composed of 12 sodium and 16 iodine atoms; the world's smallest abacus, which uses fullerene carbon molecules (C-60) as beads; a molecule consisting of 8 cesium and 8 iodine atoms.

near the cancer. In the absence of location information, it might sometimes mistakenly release poison in a cell that *seemed* to be a cancer cell. If the objective was to kill a colon cancer, for example, a cancer killer in the big toe would not release its poison no matter what its cancer sensors told it.

How Can We Get There?

The wondrous capabilities described here are, for the most part, theoretical. How can they be made real? How can we build a general-purpose, programmable manufacturing system using highly reactive, positionally controlled tools that could inexpensively manufacture most diamondoid structures?

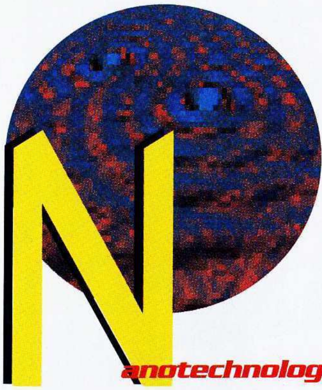
The magnitude of this challenge should not be underestimated. Present proposals for an assembler able to fabricate diamondoid structures involve hundreds of millions or billions of atoms—with no atom out of place. Even a simple robot arm, which might be composed of only a few million atoms, would have to be accompanied by other components. The robotic arms would work in a vacuum, for instance, dictating the need for a shell around the arm to maintain that vacuum. Other ancillary gadgets that will be needed include acoustic receivers, computers, pressure-actuated ratchets, and binding sites. If each operation, such as hydrogen abstraction or carbene deposition, typically handles one or a few atoms, then the error rate must be fewer than one in a billion.

Although such perfection is theoretically attainable, today's technology is not up to the task. A chemical synthesis process that chemists view as very good converts 99 percent of the reactants to the desired product. Yet that 99 percent yield represents an error rate of one in 100, which is *ten million times* less perfect than we desire for a mature nanotechnology. The synthesis of proteins from amino acids by ribosomes has an error rate of perhaps one in 10,000. DNA, by relying on extensive error detection and correction along with built-in redundancy (the molecule has two complementary strands), achieves an error rate of roughly one base in a billion when replicating itself.

No existing technology can approach this level of performance. One technique that can position individual atoms, for example, is the scanning probe microscope (SPM), in which a sharp tip is brought down to the surface of a sample so that a signal is generated that lets us map out the surface being probed, like a blind person tapping with a cane to sense the path ahead. Some SPMs literally push on the surface and note how hard the surface pushes back. Others connect the surface and probe to a voltage source, and measure the current flow when the probe gets close to the surface. A host of other probe-surface interactions can be measured, and are used to make different types of SPMs.

The SPM can not only map a surface but can change it—depositing individual atoms and molecules in a desired pattern, for example. In a well-publicized case, scientists arranged 35 xenon atoms on a nickel surface to form the letters identifying their employer: IBM. But this SPM manipulation required cooling to 4 degrees above absolute zero—not exactly ideal conditions for large-scale manufacturing. More recently, IBM scientists have precisely arranged molecules at room temperature on a copper surface. However, SPMs have error rates high enough that they must use relatively sophisticated error detection and correction methods. And while these systems can move around a few atoms or molecules, they can't manufacture large amounts of precisely structured diamond of the kind that might be

PHOTOS: IBM ZURICH LABORATORY



Nanotechnology could be used to build computer chips that are a billion times more powerful than those in today's PCs.

used to build a car or a plane.

Finally, today's SPMs are much too slow. In nature, ribosomes take tens of milliseconds to add a single amino acid to a growing protein. But if an assembler is to manufacture a copy of itself in about a day, and if this takes a few hundred million operations, then each operation must take place in a fraction of a millisecond. An SPM, by contrast, takes hours to arrange a few atoms or molecules. Rather than attempting to solve all these problems in a single giant leap, we might approach them more incrementally—developing a series of intermediate systems. One approach, for example, would be to eliminate the requirement that the assembler be made from diamondoid structures. Diamondoid is attractive, as we've seen, because of its strength, stiffness, and electrical properties. But an intermediate system need only be able to make a more advanced system, and perhaps products that are impressive in comparison with today's products. It doesn't have to be diamondoid itself.

This suggests what might be called building block–based nanotechnology. Rather than building diamond, we'll build some other material from relatively large molecular units consisting of tens, hundreds, or even thousands of atoms. Such large building blocks reduce the number of assembly steps, so fewer unit operations are required, and they need not be as reliable. Soluble building blocks that stick only to other building blocks, not to the solvent or low concentrations of contaminants, eliminate the need for working in a vacuum.

In selecting such building blocks, we have many choices: any of the many molecules that chemists have synthesized, or could reasonably synthesize, with the desired properties. Each molecular building block should have at least three sites where it can link to other building blocks. Units with two bonding sites suggest the polymers ubiquitous in biological systems, such as DNA, RNA, and proteins. Building blocks that have three bonding sites make the design of stiff three-dimensional structures much easier.

Such building blocks could be linked to each other using any one of a variety of well-understood chemical reactions. A particularly attractive possibility is the Diels-Alder reaction, in which a diene (a hydrocarbon with carbon-carbon double bond) can be made to react with a specific molecule.

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http://web.mit.edu/techreview/

Answering the Doubters

Despite the plausibility of developing nanotechnology, there are skeptics. Their criticisms, however, are poorly informed. For example, chemist David Jones, a *Nature* columnist, was quoted in *Scientific American* that the construction of a molecular assembler was doomed because individual atoms are "amazingly mobile and reactive. They will combine instantly with ambient air, water, each other, the fluid supporting the assemblers, or the assemblers themselves."

Proposals involving reactive molecular tools, however, specify that the environment should be inert—either vacuum or a noble gas; there would be no "ambient air" to react with. And because the molecular tools are positionally controlled, they will not react with each other or the assembler itself—for the same reason that a hot soldering iron does not react with the skin of the person who wields it.

I am commonly asked how long it will be before we can make molecular computers, before inexpensive photovoltaic cells bring cheap, clean solar power, before ultralightweight spacecraft dramatically lower the cost of space exploration. The scientifically correct answer is: I don't know. But looking at one technology that nanotechnology can improve—computing—gives one perspective. From electromechanical relays to vacuum tubes to transistors to integrated circuits, we have seen steady declines in the size and cost of logic elements and steady increases in their performance for the last 50 years. Extrapolation of these trends suggests that for the computer hardware revolution to stay "on schedule" will require the development of molecular manufacturing by about 2010 or 2020.

Of course, extrapolating past trends is a philosophically debatable method of technology forecasting. While no fundamental law of nature prevents us from developing nanotechnology on this schedule (or even faster), there is equally no law that says this schedule will not slip. Much worse, though, such trends imply that there is some ordained schedule—that nanotechnology will inevitably appear regardless of what we do or don't do. Nothing could be further from the truth. How long it takes to develop this technology depends very much on what we do. If we pursue it systematically, it will happen sooner. If we ignore it, or simply hope that someone will stumble over it, it will take much longer. Fortunately, by using theoretical, computational, and experimental approaches together, we can reach the goal more quickly and reliably than by using any single approach alone. Just as Boeing can design, "build," and "fly" airplanes in a computer before making them in the real world, we can do the same for molecular manufacturing. We can quickly eliminate most of the false starts and blind alleys and rapidly focus on the best approaches.

Like the first human landing on the moon, the Manhattan project, or the development of the modern computer, the advent of molecular manufacturing will require the coordinated efforts of many people for many years. How long will it take? A lot depends on when we start. ■

TECHNOLOGY UPDATE

New device turns any electrical outlet into a phone jack

Engineering breakthrough gives you unlimited phone extensions without wires or expensive installation fees

By Charles Anton

You don't have to have a teenager to appreciate having extra phone jacks. Almost everyone wishes they had more phone jacks around the house.

When I decided to put an office in my home, I called the phone company to find out how much it would cost to add extra phone jacks. Would you believe it was $158?

No more excuses. Today, there are a thousand reasons to get an extra phone jack and a thousand excuses not to get one. Now an engineering breakthrough allows you to add a jack anywhere you have an electrical outlet. Without the hassle. Without the expense. And without the miles of wires.

Like plugging in an appliance. Now you can add extensions with a remarkable new device called the Wireless Phone Jack. It allows you to convert your phone signal into an FM signal and then broadcast it over your home's existing electrical wiring.

Just plug the transmitter into a phone jack and an electrical outlet. You can then insert a receiver into any outlet anywhere in your house. You'll be able to move your phone to rooms or areas that have never had jacks before.

Clear reception at any distance. The Wireless Phone Jack uses your home's existing electrical wiring to transmit signals. This gives you sound quality that far exceeds cordless phones. It even exceeds the quality of previous devices. In fact, the Wireless Phone Jack has ten times the power of its predecessor.

Your range extends as far as you have electrical outlets: five feet or five hundred feet. If you have an outlet, you can turn it into a phone jack—no matter how far away it is. The Wireless Phone Jack's advanced companding noise reduction features guarantee you crystal-clear reception throughout even the largest home.

Privacy guarantee. You can use The Wireless Phone Jack in any electrical outlet in or around your home, even if it's on a different circuit than the transmitter. Each Wireless Phone Jack uses one of 65,000 different security codes. You can be assured that only your receiver will be able to pick up transmissions from your transmitter.

Is the Wireless Phone Jack right for you?

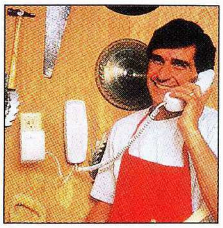
The Wireless Phone Jack works with any single-line phone device. Almost anyone could use it, especially if…

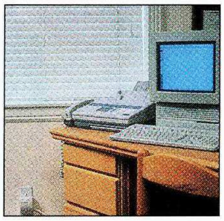
- **Few jacks.** *You want more phone extensions without the hassle and expense of calling the phone company.*
- **Bad location.** *You have jacks, but not where you need them most, like in the kitchen, garage, home office or outside on the deck.*
- **Renting.** *You want to add extensions, but you don't want to pay each time you move.*
- **Other phone devices.** *You have an answering machine, modem or fax machine you want to move to a more convenient place.*

The Wireless Phone Jack System consists of a transmitter (right) and a receiver (left). One transmitter will operate an unlimited number of receivers.

Unlimited extensions—no monthly charge. Most phone lines can only handle up to five extensions with regular phone jacks. Not with the Wireless Phone Jack. All you need is one transmitter, and you can add as many receivers as you want. Six, ten, there's no limit. And with the Wireless Phone Jack, you'll never get a monthly charge for the extra receivers.

Works with any phone device. This breakthrough technology will fulfill all of your single-line phone needs. It has a special digital interface for use with your fax machine or modem. You can even use it with your answering machine just by plugging it into the Wireless Phone Jack receiver.





The Wireless Phone Jack lets you add a phone, modem, fax machine or answering machine almost anywhere.

Special factory-direct offer. To introduce this new technology, we are offering a special factory-direct package. For a limited time, the transmitter is only $49. One transmitter works an unlimited number of receivers priced at $49 for the first one and $39 for each additional receiver. Plus, with any Wireless Phone Jack purchase, we'll throw in a phone card with 30 minutes of long distance (a $30 value) for only $9.95!

Try it risk-free. The Wireless Phone Jack is backed by Comtrad's exclusive 30-day risk-free home trial. If you're not completely satisfied, return it for a full "No Questions Asked" refund. It is also backed by a one-year manufacturer's limited warranty. Most orders are processed within 72 hours and shipped UPS.

Wireless Phone Jack transmitter ...$49 $4 S&H
Wireless Phone Jack receiver ....$49 $4 S&H
save $10 on each additional receiver—$39

30-minute long distance phone card.......~~$30~~
$9.95 with Wireless Phone Jack purchase

Please mention promotional code 017-10463.

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The National Ignition Facility

Buyer Beware

IN SEPTEMBER 1996, WHEN PRESIDENT CLINTON SIGNED THE "ZERO-YIELD" comprehensive test ban—a treaty outlawing all nuclear explosions—he managed to win over the treaty's strongest opponents. But this support did not come for free.

The Pentagon, the Joint Chiefs of Staff, and the weapons labs conditioned their approval of a test ban on a number of "safeguards." As part of the agreement, Clinton declared that if ever a high level of confidence in a certain type of nuclear weapon could no longer be certified, he would be prepared to invoke the supreme national interest clause under the test ban and conduct whatever nuclear testing may be required. "Exercising this right, however, is a decision I believe I or any future president will not have to make," Clinton's official statement read. His optimism may have been connected with another condition imposed by the military and the labs: full funding for the Department of Energy's Stockpile Stewardship and Management Program "over the next decade and beyond." The program is slated to receive about $40 billion over the next 10 years.

BY TOM ZAMORA COLLINA

The federal government's planned laser fusion center is being sold as an essential tool for preserving the aging U.S. nuclear arsenal. But that's not what the taxpayer is getting.

ILLUSTRATIONS BY SUSAN LEVAN

The stewardship program is supposed to help maintain the safety, reliability, and performance of the nuclear arsenal so that no U.S. president has to resume nuclear testing. It would achieve this goal by keeping three separate nuclear weapons laboratories in operation—Los Alamos and Sandia in New Mexico, and Lawrence Livermore in California—and by spending $3 billion to build a variety of new experimental facilities to simulate different aspects of a nuclear explosion. Some facilities would address the primary stage of a warhead and some the secondary stage (in thermonuclear weapons, a primary, or fission, stage produces x-rays to implode the secondary, which releases energy through fusion); other facilities would simulate the effects of nuclear explosions on military hardware. About a third of this funding would be spent on new supercomputers to make the most use of the new facilities and to tie the three labs together into one "superlab."

The flagship of this armada of new facilities is the National Ignition Facility, or NIF, a $1.1 billion laser fusion laboratory slated for construction by 2002 at Livermore. The project has already received more than $250 million, and its total cost over 30 years would be $4.5 billion, not accounting for inflation. The decision to start construction will be made in mid-1997.

The trouble is, the Department of Energy has yet to offer a convincing rationale for why this most expensive of stewardship facilities should be built. For example, one of NIF's main purposes, according to DOE, is to help assess age-related changes in warhead secondaries and determine their impact on the reliability of the weapons. But secondary components of nuclear warheads have never worn out, and the ones we have today could probably last for decades; there is no rush to build NIF. Moreover, problems with secondaries would have a relatively minor impact on overall warhead performance. And when defects do appear, NIF may not play much of a role in fixing them.

The Energy Department foresees other, subsidiary missions for NIF. One is to maintain a cadre of scientists to assess future problems with the arsenal or design new weapons if the Cold War heats up again. Another mission is to allow civilian research on fusion energy and other areas of basic and applied science. But each of these justifications for NIF is fraught with risky or unwarranted assumptions.

Few question the need for a stewardship program to monitor the nuclear arsenal as it ages, and to deal with any problems that might crop up. The issue is what kind of a stewardship program the nation needs, and what new facilities—if any—are required to do the job. NIF is the most glaring example of a stewardship facility that is not essential to the mission of preserving the nation's nuclear arsenal.

"AGING" WEAPONS

The most direct link between NIF and stewardship is the laser facility's presumed role in assessing problems that might arise in aging secondaries. The hope is that the facility will be able to reproduce the conditions found in an exploding thermonuclear weapon, but on a much smaller scale.

NIF is an "inertial confinement fusion" facility. It would use the largest and most powerful laser in the world, made up of 192 separate beams, to deliver a laser pulse of 1.8 megajoules of energy (far more than the 40 kilojoules now available on Livermore's NOVA laser). This energy would be used to implode deuterium-tritium pellets to produce billionth-of-a-second bursts of fusion energy for study. By improving our knowledge of weapons physics, the argument goes, NIF will help scientists gauge the seriousness of defects that might occur as the stockpile grows older.

The aging of the stockpile is related to the end of nuclear testing. Over the last 40 years, the United States continually upgraded and replaced older warheads by developing new designs with the help of nuclear tests. Without such tests, the Pentagon does not currently plan to replace existing warhead types with new ones in the future. According to Harold Smith, assistant to the secretary of defense for nuclear, chemical, and biological weapons, quoted in the May 9, 1996, issue of *Inside the Pentagon*: "There are no new [designs for] warheads. There cannot be. Because if you cannot test, you cannot develop new warheads. That is almost the eleventh commandment as given to Moses on Mount Sinai."

As long as this sentiment is so strongly held in the Pentagon, the average age of the stockpile will grow steadily from 13 years today to 20 years by 2005, taking into account the retirement of some of the older weapons. (If the United States and Russia agree to further cuts in their arsenals, this average would fall, since older weapons would likely be eliminated first.) Although 20 years is often characterized as the maximum life of a weapon, it is actually the shortest lifespan contemplated. The Department of Energy's stockpile management program—which is responsible for manufacturing new warhead parts as the stewardship program deems necessary— states in its February 1996 "Draft Analysis of Stockpile Management Alternatives" that nuclear components "are expected to have service lives significantly in excess of their minimum design life of 20 to 25 years." According to the report, "Experience indicates that weapons can remain in the

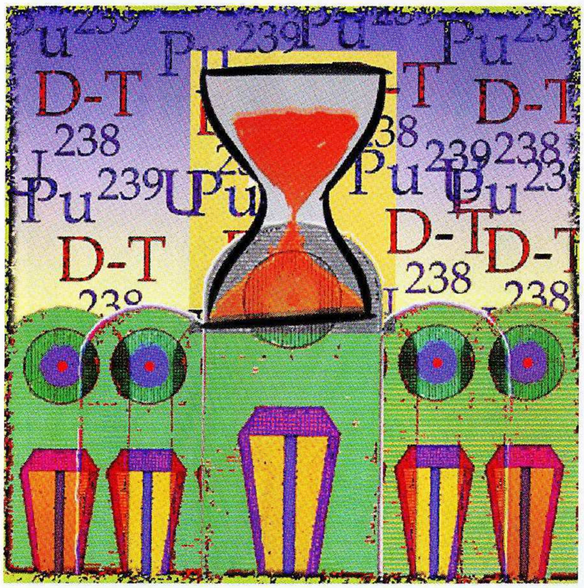
TOM ZAMORA COLLINA is executive director of the Institute for Science and International Security, a nongovernmental research organization in Washington, D.C., focusing on issues relating to nuclear weapons.

stockpile well beyond their minimum design lifetime."

Since 1958, an Energy Department effort known as the Stockpile Evaluation Program (SEP) has compiled a detailed record of the condition of nuclear weapons. Significantly, SEP has yet to turn up any evidence that age-related defects appear with greater frequency over time. Nor is there any sign that warhead secondaries, the components most relevant to NIF, are prone to age-related defects at all. If anything, secondaries appear to be the least vulnerable nuclear components of the weapon.

The warhead components most relevant to NIF have never worn out and could probably last for decades.

Under SEP, 11 sample warheads of each weapon type are taken out of the stockpile every year, according to "Stockpile Surveillance: Past and Future," a September 1995 report by the three weapons labs. The samples are disassembled and inspected, and the non-nuclear components are subjected to laboratory and flight tests. As a rule, the nuclear explosive package from one sample per year per weapon type is destructively examined (for example, the plutonium components are cut up for metallurgical analysis) by whichever weapons lab produced the warhead. This sample is then retired from the stockpile and must be replaced with components that are either held in reserve or, if spares are not available, newly produced. The other 10 samples per warhead type are returned to the stockpile with original nuclear components and replacement non-nuclear parts as needed. This process begins and ends at the Pantex plant near Amarillo, Texas.



Of the 70,000 or so U.S. nuclear weapons produced since 1958, the Stockpile Evaluation Program has examined more than 13,800 weapons of 45 different types. About 800 distinct sorts of findings have warranted further investigation. Of these, about 400 were deemed "actionable," meaning that the finding resulted in corrective measures (to the weapon itself or to the production process) or in a downgrading of the weapon's assumed reliability or yield. Most such findings have occurred in the first few years of a weapon's life as a result of problems in design, fabrication, or production—problems that tend to get worked out early on. As the weapons age, fewer actionable findings appear. Using past experience to project the future health of the stockpile, the weapons labs estimate in their joint report that over the next 10 years there will be an average of one to two actionable findings per year, one of which will result in a change to a warhead.

These numbers, however, do not distinguish between production problems and age-related defects, such as cracks, corrosion, and the like. Production problems are unlikely to reappear, and aging problems serious enough to correct have been restricted almost entirely to non-nuclear components, such as detonators, cables, and neutron generators. If found to be defective, all these parts can be newly fabricated and fully tested.

The challenge today for the laboratories is to assess the nuclear parts (primary "pits" and secondaries) of the warhead that can no longer be tested in actual detonations. So far, the nuclear heart of the primary—the pit, made of plutonium, uranium, and beryllium—has received a clean bill of health. While acknowledging that few data are available for pits older than 25 years, the stockpile management program states in its February 1996 draft analysis that "no age related problem has been observed in pits up to 30 years in age." Which is not to suggest these components are immortal; at some point, the plutonium's radioactive decay could lead to performance problems. According to a senior scientist in the Energy Department's stockpile management program, pits may last "40, 60, 100 years, but not 1,000."

But what about secondaries, the supposed deterioration of which serves as the raison d'être for NIF? Here the record is similarly encouraging. Secondaries consist of uranium, lithium deuteride, and other subcomponents isolated from the external environment in a sealed can. Although the materials can still react with each other, this has not been a significant problem, according to DOE documents obtained by the Institute for Energy and Environmental Research in Tacoma Park, Md. Examinations of secondaries since 1958 have uncovered only two types

nation to make a sophisticated nuclear weapon, but it could help build expertise. "Should a non-nuclear state decide to 'go nuclear,' " says Ray Kidder, a laser fusion pioneer and weapons physicist who recently retired from Livermore, "the existence of a cadre of people already experienced in many of the skills needed for designing nuclear weapons could, depending on the circumstances, materially reduce the time required to acquire them." Just as the United States wants to use NIF to maintain a corps of experienced scientists, so might other nations use it to develop one.

NIF would increase the number of scientists, both in the U.S. and abroad, who are familiar with computer codes pertinent to nuclear weapons.

On the other side, non-nuclear states that were involved in the Geneva talks on the Comprehensive Test Ban Treaty have expressed serious concern that facilities like NIF will help nuclear states design new weapons without testing. India's ambassador to the Conference on Disarmament, Arundhati Ghose, has warned: "The CTBT must be a truly comprehensive treaty, that is, a treaty which bans all nuclear testing without leaving any loopholes that would permit nuclear weapon states to continue refining and developing their nuclear arsenals at their test sites and their laboratories." The Department of Energy has sought to allay these concerns by stating that "NIF cannot proof-test any nuclear device and therefore cannot act as a replacement for full-up nuclear testing in the stockpiling of any nuclear weapons."

This is true, but the stewardship program in its totality would provide U.S. weapons designers with more data than they have ever had, short of actual nuclear tests. The worry is that over time the labs may feel more confident about their ability to make changes to existing warheads—even to design all-new weapons—on the basis of computer simulations and experiments conducted at NIF and other facilities. On the one hand, the stewardship program tries to downplay this possibility, asserting in its "Programmatic Environmental Impact Statement" that "the issue of new-design weapons is separate from DOE's need to perform modifications to existing weapons that require research, design, development, and testing." On the other hand, the line between "modifications" and "new design" is not clear. Moreover, DOE admits that "it would be unreasonable to say that these stewardship capabilities could not be applied to the design of new weapons, albeit with less confidence than if new weapons could be nuclear tested."

NIF's implications for global security may be worrisome and its contribution to national security may be weak, but the project does have one strong suit: politics. NIF and the stewardship program are designed to secure support in the Senate for ratification of the comprehensive test ban. And because it may be years before the Senate considers CTB ratification, NIF could have plenty of time to soak up funds and begin construction. By that time, the project may be untouchable.

Or not. Once the test ban is ratified, congressional members looking to cut wasteful federal spending may see the program as an attractive target. If so, hundreds of millions of dollars would have been spent on a facility that may never be finished—the superconducting supercollider revisited. Instead of building expensive mega-facilities like NIF, the stewardship program needs to focus its resources on monitoring the stockpile and replacing suspect parts. The Energy Department could take a wait-and-see approach: continue to depend on the less powerful (but paid-for) NOVA laser for fusion-related experiments, and keep sample secondaries from older weapons under surveillance to find aging problems earlier than they would appear in the active arsenal. This way, we could wait for age-related defects to appear before breaking ground on NIF.

In the meantime, Congress should not let itself be fooled into believing that the facility is necessary for "national security." NIF may be nice to have, but for the foreseeable future we can get along without it. ■

of age-related defect, neither of them serious enough to correct. In fact, the stockpile management program acknowledges that "there has been no degradation or concern for performance for any of the weapons in the stockpile of 2004 and beyond."

The facility may attract new talent to work on nuclear physics but not necessarily to do weapons work, as is hoped.

Even if aging problems with secondaries appear, these warhead stages have the advantage of simplicity and reliability. Says the DOE senior scientist, "Once the primary [detonates], the secondary will also, even if it has some defects." Unlike the primary stage, which drives the nuclear explosion, the performance of the secondary appears to be relatively insensitive to age-related changes.

If the historical record is any indication of future performance, aging of nuclear components seems likely to remain a rare problem for the foreseeable future. With an average stockpile age of 13 years (the oldest deployed warheads are now 18 years old), and the knowledge that nuclear components can last well beyond the design life of the overall warhead, we are possibly decades away from encountering any significant age-related problems with nuclear components. Hence there is no rush to build new facilities to address aging problems, especially with secondaries.

WEAK JUSTIFICATIONS

When and if serious defects are found in secondaries, NIF's contribution to fixing them would probably be minimal. According to the "Programmatic Environmental Impact Statement" published by DOE in September 1996: "If an unanticipated change relevant to the high-energy-density phase of weapon operation is observed in the weapon surveillance program [SEP], specially designed NIF experiments could aid weapons scientists in validating aspects of their integrated computer models to assess whether that change would adversely impact the weapon's reliability."

The trouble with this justification is that it is not clear how helpful NIF would be in assessing age-related changes. Moreover, such assessments are not even necessary. A simpler approach is merely to build a new part. If the labs are unsure how significant a defect is, the management program can have a replacement part manufactured at the Oak Ridge plant in Tennessee, which will maintain its capacity to build secondary components. According to the Pentagon's Smith, "The way you take care of aging is, in extremis, you build a new one. And that's what we'll do." Alternatively, the part could be replaced by a spare in reserve.

Proponents also suggest that experimental results from NIF could be used to improve computer codes to determine whether rebuilt parts would behave as expected. But that is not a great concern for secondaries. According to a Los Alamos scientist, "secondaries are much more forgiving than primaries." And incorporating NIF data into these codes would entail some risk. Computer codes for designing and simulating nuclear weapons have been "normalized" to nuclear test results—that is, the codes are based on data from actual explosions. Modifying the codes on the basis of NIF experiments could distance them from past test experience, possibly rendering them less reliable.

If NIF is not needed to fix warhead problems, then why do we need it at all? According to DOE, the broader NIF stewardship mission is to act as a "magnet" to draw fresh talent to Livermore and keep current weapons designers engaged, making it easier to assess warhead problems and design new warheads if international relations go sour. As Victor Reis, assistant secretary of energy for defense programs and architect of the stewardship program, testified before Congress in 1994: "The whole idea of lasers is for understanding the physics of secondaries, but also more particularly, for maintaining that cadre of scientists who both understand the fusion process and all the things that go along with that. . . . The stewards really are more important than the equipment."

But while NIF may succeed in attracting new talent to work on nuclear physics, it is not clear that it would attract

people who want to do weapons work. Supercomputer experience is more relevant to the career of a budding weapons designer than a job pushing the envelope of fusion research. So it seems likely that the $93 million IBM supercomputer Livermore is due to receive in 1998—a machine that will run 300 times faster than any existing computer—will play more of a "magnet" role than NIF. If we are genuinely concerned about maintaining expertise in weapons physics, $4.5 billion in salary increases for weapons designers might be money better spent.

But perhaps the concern itself is misguided. If more nuclear weapons were needed in a renewed Cold War, the United States could build them using existing designs, a job that would not require advances in nuclear weapons physics. In the worst and most unlikely case—new types of warheads are needed to counter an adversary's qualitative leap—design teams could be reconstituted at the labs, which, even without NIF, will employ weapons scientists in design-related activities. The experience gained from the more than 1,000 nuclear tests the United States conducted before the cessation of such activities, plus the renewed testing that would clearly be warranted in such a crisis, would give the reconstituted design teams a huge database on which to draw.

Many scientists outside the defense arena find NIF very exciting. If successful, its increased power and greater implosion symmetry over Livermore's NOVA could make it the first fusion facility to achieve ignition—a state in which more energy is produced than is needed to create the reaction in the first place. This would be an important milestone in the development of fusion power for civilian energy production. But there are two problems with using the prospect of civilian fusion experiments to justify NIF. One is a matter of prudence, the other a matter of public accountability.

Investing huge sums in a fusion facility is a risky proposition. For one thing, there is no guarantee that NIF, even with its 192 separate beams, can achieve the exquisite symmetry of implosion needed to produce an efficient fusion reaction. Timothy Coffey, director of research at the Naval Research Laboratory, who served on a 1994 NIF review panel, has expressed doubts about the prospects for success, adding: "If ignition is not achieved, then more than one billion dollars will have been wasted since the residual capabilities of the facility could have been far more easily achieved by different and much less expensive techniques."

Exemplifying the technical difficulties the project could face, a glass lens in a NIF prototype laser imploded in September, causing the laser to be shut down for the second time in 17 months. Researchers have less than a year to correct the problem before construction begins.

Many other obstacles must also be overcome before fusion energy runs our refrigerators. Lasers are not expected to meet the requirements—efficiency, high rate of repetitive firing, and long lifetime—of a future fusion energy source. Other means of driving the reaction, such as a heavy-ion accelerator, may have to be developed. A 1995 Energy Department–sponsored task force chaired by Robert Galvin of Motorola warned—even though it ultimately favored NIF—that "there is a low probability that inertial fusion will become a useful source of energy in the foreseeable future."

Still, NIF has become a favorite of researchers in a number of basic and applied science areas. It could yield insights into supernovas, for example, as well as aid in the study of materials under high pressure, dense plasmas, and radiation sources. Prominent physicists recently wrote to Rep. Ron Dellums (D-Calif.), the ranking Democrat on the House National Security Committee, urging his support for the project on the grounds that it would be "important to fusion energy and basic science."

This is where accountability comes in. NIF may be a great asset to fusion research and other fields, but it is not being funded as a basic-science tool. The facility has been promoted for its nuclear-stewardship role first and its civilian role second. So if the program's real value stems from its contribution to basic science, then it ought to be subjected to the same funding criteria as other large basic-science projects. Would NIF survive close congressional scrutiny if it couldn't hide behind a national security smoke screen? The cancellation of the superconducting supercollider is proof enough that expensive basic-science projects are a hard sell in Congress these days.

NIF AND PROLIFERATION

But if NIF is a waste of money or a less-than-straightforward use of public funds, is it actually harmful? From the standpoint of proliferation, it could be. Fusion research could further the spread of nuclear weapons, because the computer codes that are used to predict the behavior of the facility's targets (the pellets that the laser beams fire on) are similar to codes for designing the fusion components of weapons. NIF would increase the number of scientists familiar with such codes in the United States and abroad.

Not only is NIF meant to be a multiuse facility open to international researchers (accessibility is one of its major selling points), but other nations such as Germany, Japan, and Israel have built or may build their own facilities for inertial confinement fusion. The Energy Department plans to institute some safeguards: scientists from states that have not signed the Nuclear Nonproliferation Treaty might be barred from using NIF, and the department could reject proposed experiments that are directly relevant to weapons development. However, since all experiments in inertial confinement fusion have some relevance to nuclear weapons, information control will be difficult.

The bottom line is that NIF would not by itself allow a

Climb...

To the Roof of Africa at 19,340 feet
Kilimanjaro Climb—Sept 18-25, 1997
Tanzania Safari—Sept 25-Oct 4, 1997

This September join us for an exciting 7 day expedition to reach the summit of Mount Kilimanjaro. Following the climb, join MIT Professor Emeritus Patrick Leehey as he leads our group on safari in Tanzania through the Ngorongoro Crater—Africa's "Garden of Eden"—Lake Manyara National Park and Tarangire National Park. Professor Leehey, of MIT's Harold Edgerton Center, will take his photographic expertise and knowledge of the area on the road as we discover and photograph the beauty of Tanzania. (Safari and climb programs may be purchased separately.)

Explore...

The Mountains and Valleys of Switzerland during a Swiss Walking Tour—Sept 8-16, 1997

The mountains of Switzerland are a spectacular backdrop for an endless number of trails and footpaths which we will explore at a leisurely pace. Utilizing regional trains, cable cars, funiculars and even postal buses we will reach gentle walking paths high in the mountains. The towns of Engelberg, Zermatt and Lucerne will be visited.

Learn...

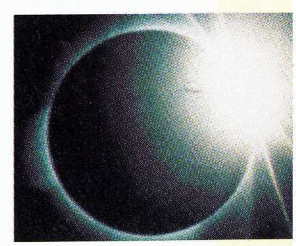
About the Historic Tradition & Modern Technology of Scotland—Sept 15-25, 1997

MIT Professor Emeritus Ernst Frankel will lead the group as we learn about the work of architect Charles Rennie Mackintosh and visit Glasgow's and Edinburgh's fine museums and modern centers of industry. We will also explore the scenic Grampian Highlands and visit Stirling Castle, Scone Palace and the Glenfiddich Distillery. Join us on a relaxing, informative tour of bonnie Scotland.

Witness...

A Total Solar Eclipse during a Caribbean Cruise—Feb 23-Mar 5, 1998

On February 26th, as we reach the coordinates 11° 56' north latitude, 70°19' west longitude, stars and planets will become visible as we observe one of Nature's most awesome spectacles, a Total Solar Eclipse. Joining us on board will be astronomers, meteorologists and expert photographers who will prepare us for the event. We will travel on board the Stella Solaris. Our ports of corts include Curaçao, Aruba, Jamaica and Cozumel.



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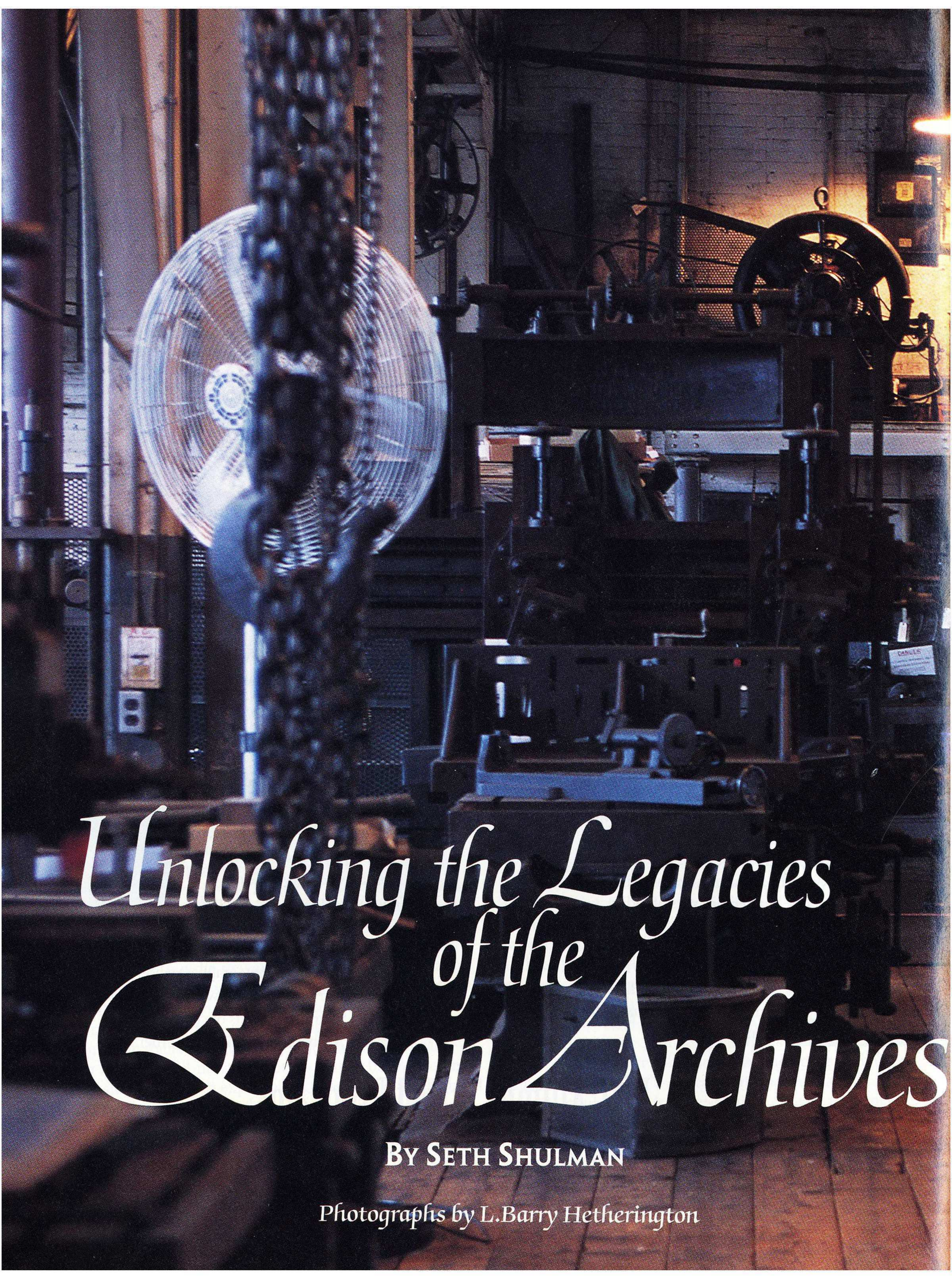
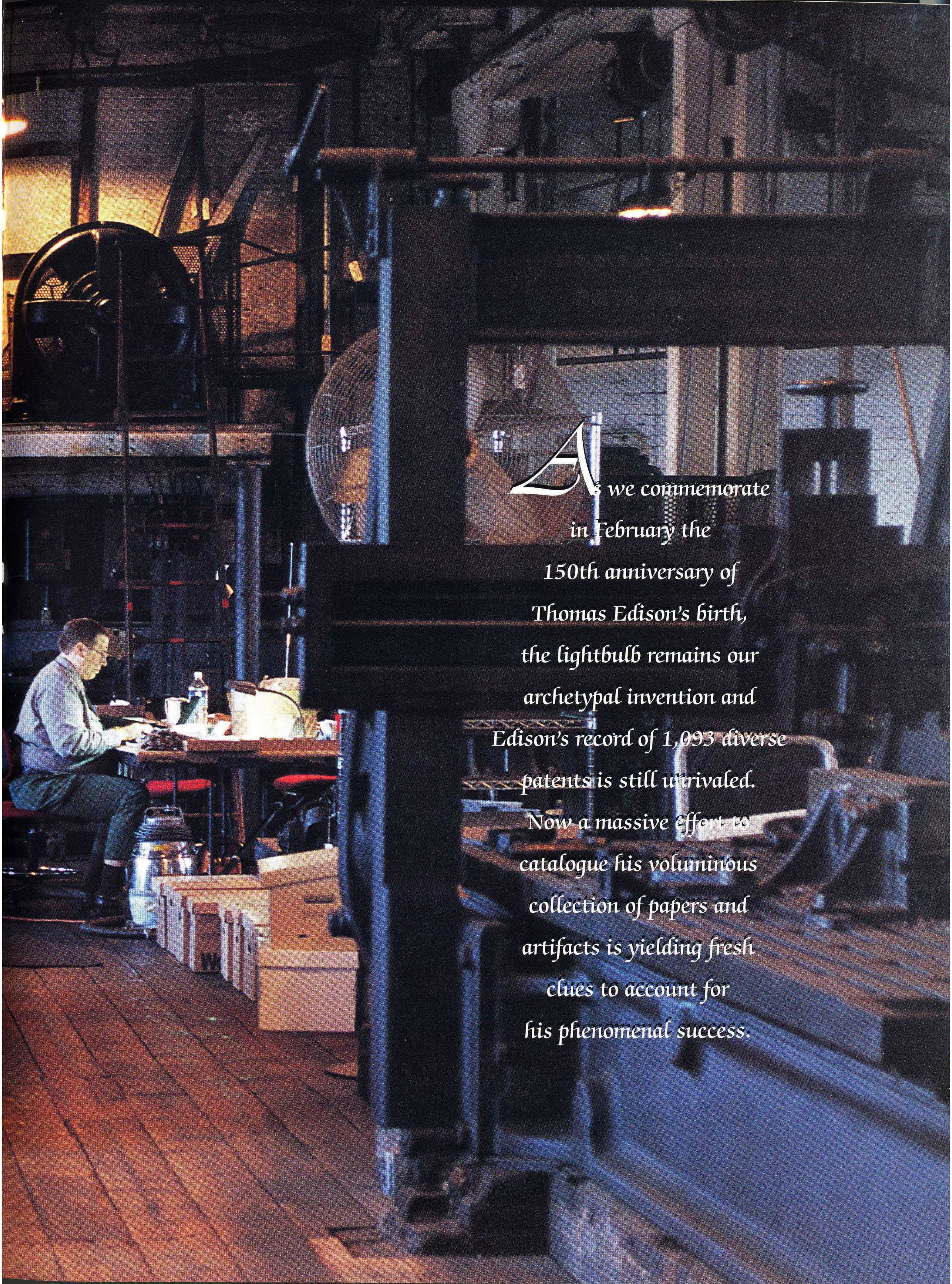


Unlocking the Legacies of the Edison Archives

By Seth Shulman

Photographs by L.Barry Hetherington



As we commemorate in February the 150th anniversary of Thomas Edison's birth, the lightbulb remains our archetypal invention and Edison's record of 1,093 diverse patents is still unrivaled. Now a massive effort to catalogue his voluminous collection of papers and artifacts is yielding fresh clues to account for his phenomenal success.

LEONARD DEGRAAF, sporting the familiar beige and green uniform of the U.S. National Park Service, leads the way through a narrow subterranean passageway to one of the country's invaluable and rarely viewed wonders. Rounding a final turn, DeGraaf points to the chamber before him. "This is always a thrill for me, no matter how many times I come here," he says in the kind of hushed, reverent tone you might expect from a park ranger approaching the rim of the Grand Canyon or spotting a bald eagle. DeGraaf's enthusiasm, however, is directed toward the massively thick steel door of an underground bank vault.

Unlike many of his park-ranger colleagues, DeGraaf is neither a forester nor a geologist but a historian of technology. The passageways of his prized grotto, some 15 feet below the barren, paved courtyard of an aging laboratory complex, are human-made and lined floor to ceiling with shelves of papers. DeGraaf pulls open the vault's thick steel portal to reveal a collection of some of technology's most fertile germinations: the 3,500 handwritten notebooks of Thomas Alva Edison. Now administered by the U.S. Park Service, the vault is the heart of the Edison Archives, a bomb-resistant bunker built below the famous inventor's laboratory in West Orange, N.J.

DeGraaf explains that Edison and his colleagues used the notebooks as a daily log of their experiments just as many modern labs do. But Edison also recorded his musings about cosmology, observations of the natural world, sketches, even occasional poetry. In these pages, for instance, Edison not only details the steps leading to his successful prototype of the incandescent lightbulb but also his forays into everything from x-rays to air travel. Spanning most of his astonishing six-decade career, the vast collection offers an opportunity, rare in its detail and depth, to peer inside the mind of one of history's greatest inventors.

What makes the notebooks all the more fascinating, as DeGraaf knows intimately, is the fact that the Edison estate, bestowed to the Park Service in 1955, also contains a remarkably diverse collection of related documents and artifacts, including correspondence, legal records, prototypes, and Edison's complete library of books and articles, many scrawled with his wide-ranging and often irreverent marginalia. "We are blessed here with one of the most complete personal archives in the history of technology," DeGraaf says. "A researcher here can trace an idea from its earliest conception through to its full-scale development and production."

Historians have uncovered new evidence of Edison's enormous talent for appropriating techniques that failed in one instance and using them to great effect in another.

Complete as the collection may be, though, the locked bunker and bank vault serve as an unfortunately apt metaphor for the sequestered archive. As a result of some measure of neglect, underfunding, and incompetence, only a few individuals have ever viewed the bulk of the papers and memorabilia. Some 65 years since Edison's death, roughly half of the lab's 5 million documents and 400,000 artifacts have yet to be catalogued. And despite some 17 years of concerted archival work by the Thomas Edison Papers Project, a joint effort of the Park Service and historians at Rutgers University, only slightly more than a third of Edison's remarkable notebooks—the chronologically earliest—have been reproduced on microfilm so they can be inspected by more than the tiniest handful of scholars. DeGraaf concedes the obvious: "The material just hasn't been accessible," he says. "It has been a very underutilized resource."

Edison's papers may remain largely hidden from public view, but we live daily with his overpowering imprint on our technological world. Most people know that the development by Edison and his colleagues of a working incandescent lightbulb spawned the omnipresent electric-power grid whose major components often still bear his name. But Edison's contributions go well beyond that linchpin of modern technological society: like a runner who leaves even his closest competitors in the dust, Edison's astonishing record of 1,093 patents far outpaces that of all other inventors before or since, and the breadth of these contributions is equally remarkable. His invention of the phonograph, for example, made possible the music-recording industry just as moving pictures, also his brainchild, eventually put Hollywood on the map. Less well known are Edison's invention of the microphone

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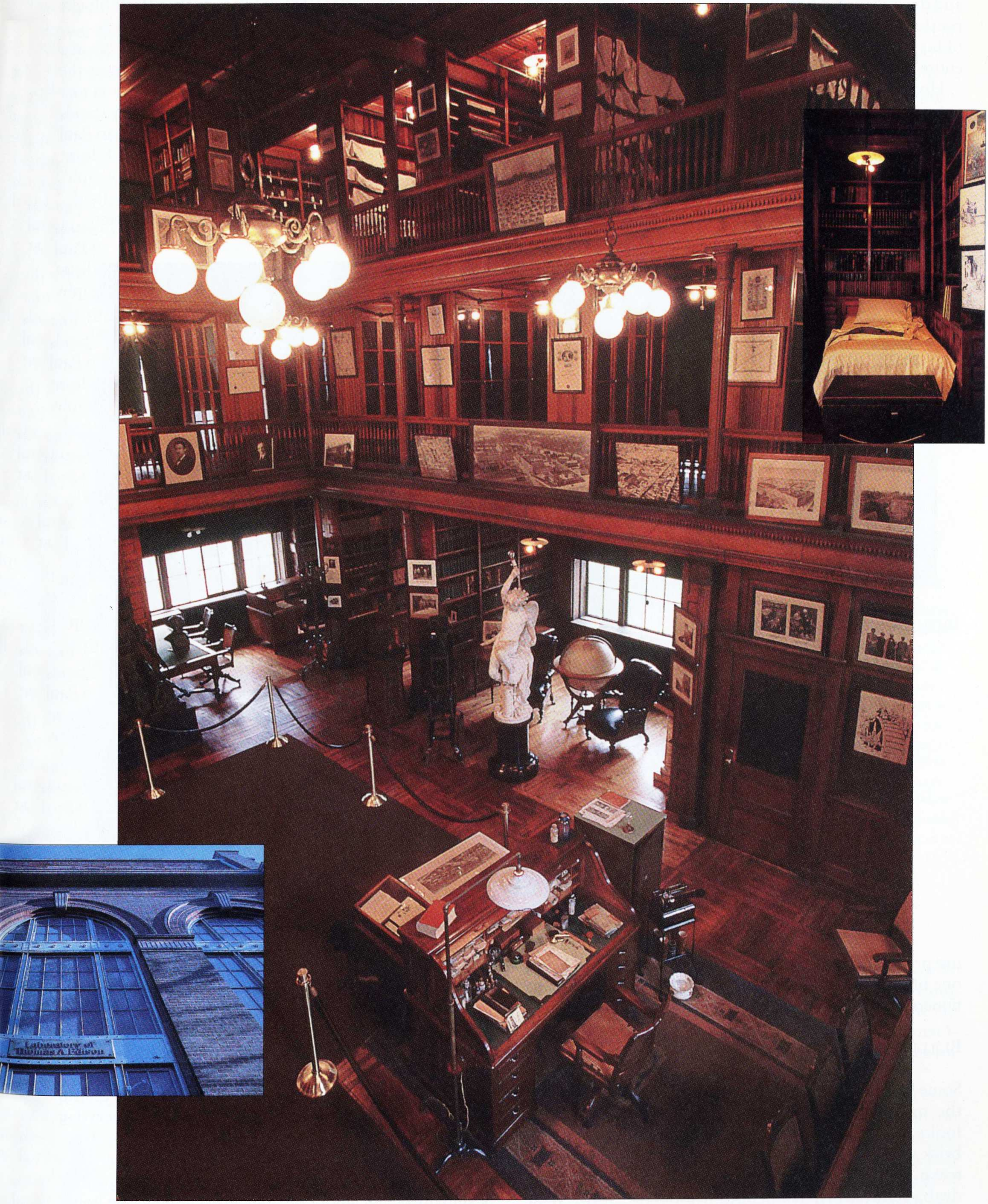
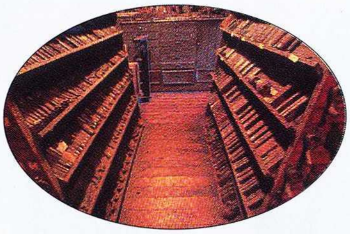
SETH SHULMAN, a contributing writer for Technology Review, *is working on a book chronicling the emerging battles over knowledge assets on the high-tech frontier.*



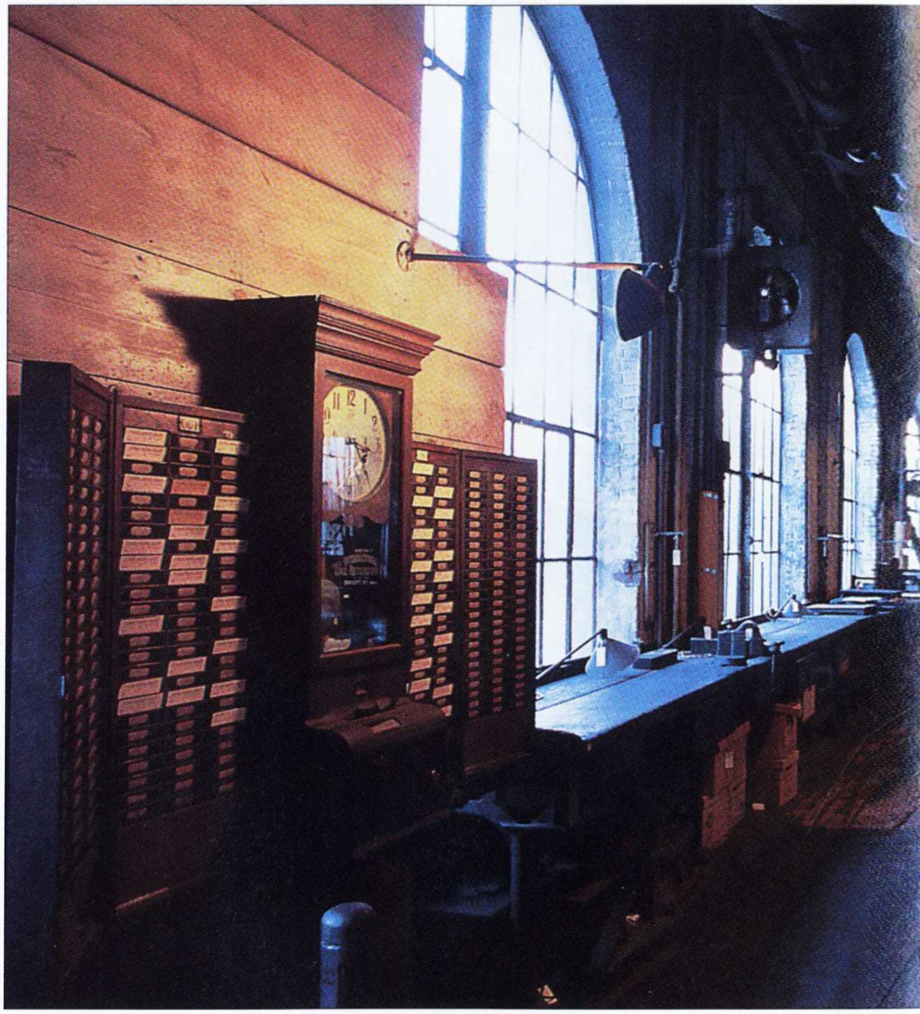
THE EXTERIOR EDIFICE (NEAR INSET) AND THREE-STORY ORIGINAL LIBRARY OF EDISON'S AMBITIOUS LABORATORY COMPLEX IN WEST ORANGE, N.J. TOP INSET: THE BED THE INVENTOR KEPT HANDY FOR ALL-NIGHTERS.

and the mimeograph and his key advances in batteries. His portfolio even included a patent on poured concrete, part of his half-realized plan to build the structural shell of an entire middle-class house in just six hours.

How could a maverick with virtually no formal education pull off such an uncanny string of important inventions? Rather than settle for the view popular in his day—promoted largely by Edison himself—that his success derived from some combination of technological genius and single-minded perseverance, the few historians who do have access to Edison's papers are focusing primarily on the innovative strategies he employed as one of the earliest—and still one of the boldest—practitioners of modern large-scale R&D.



Conscious that he was forging a new path for large-scale R&D, Edison built a complex that carried "a stock of almost every conceivable material" so he could "build anything from a lady's watch to a locomotive."



Building an "Invention Factory"

Some 40 minutes from Manhattan along Interstate 280, the middle-class community of West Orange, N.J., looks much the same as it did in Edison's day. Tired brick storefronts line a depressed but still viable downtown. A few blocks away, nestled unobtrusively in a drab, semi-industrial neighborhood, Edison's West Orange facility, built in 1887, fills two fenced-off blocks with a cluster of vaguely fortresslike brick buildings.

The very creation of an independent laboratory here in a prosaic New Jersey suburb is nearly as noteworthy as the work conducted inside. Bearing no visible connection to a university or corporate headquarters, the laboratory stands alone both visually and figuratively. Rutgers historian Paul Israel, one of the editors working on the Thomas Edison Papers Project and the author of a forthcoming biography of Edison—the first based on extensive access to the archives—explains some of the vision behind the freestanding laboratory. "Edison was one of the first," he says, "to understand that the invention process could be organized."

In a posthumous work on invention published in 1993, the eminent computer scientist Norbert Wiener attests that Edison's most lasting innovation "was the invention of the industrial scientific laboratory in which a moderately large trained crew of technicians was directed by a central mind towards the making of inventions as an everyday business."

Many of the techniques Edison would use to run his R&D operation were honed in nearby Menlo Park, where he initially built a laboratory and adjacent boarding house

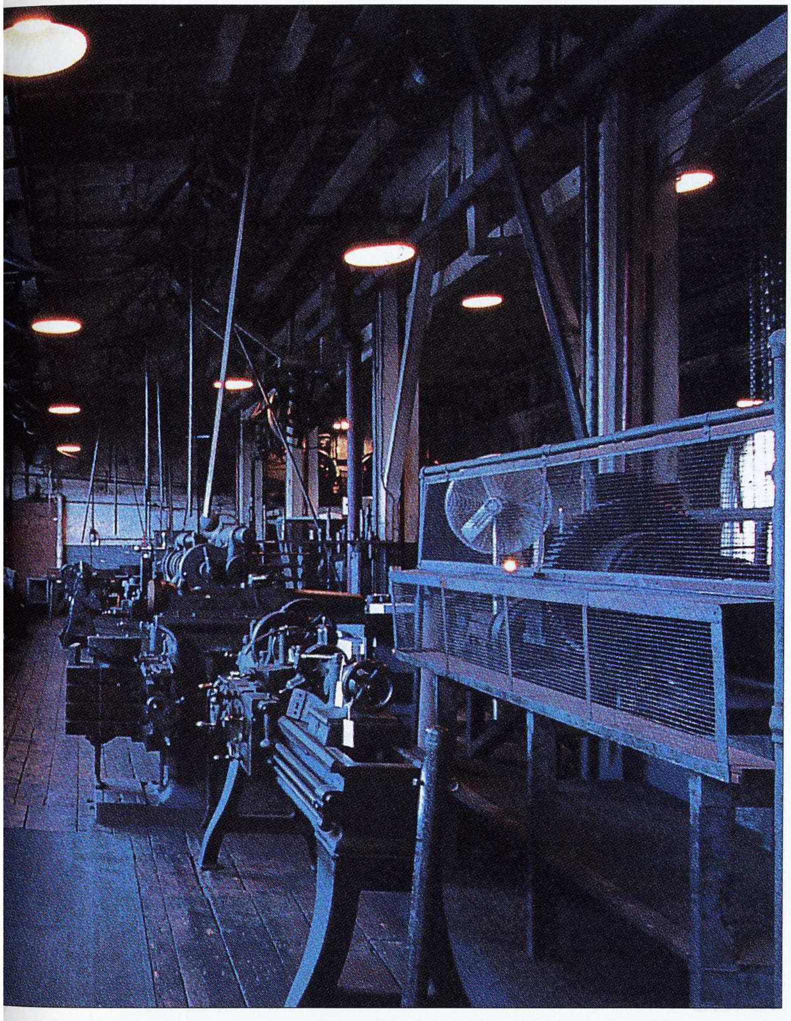
for his workers. There Edison and a dozen colleagues worked in teams to tackle as many as 40 separate projects at a time, including the lightbulb. In 1876, with typical bravado, Edison promised that the enterprise would yield a "minor invention every ten days and a big thing every six months or so." Remarkably, Edison averaged close to this success rate throughout most of the ensuing four decades.

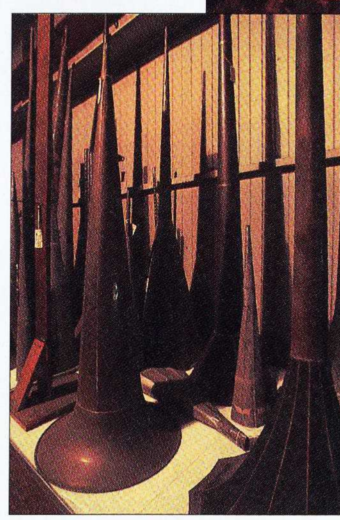
Cashing in on the initial fame and financial success afforded by his invention of the lightbulb, Edison seized the opportunity in his West Orange laboratory to more completely realize his vision of what he called his "invention factory." He chose the rural site near his newly purchased estate because it offered lots of space upon which to build yet proximity to Manhattan's supply of materials, workers, and capital. Here, conscious that he was forging a new path for commercially oriented technological research, Edison built one of the world's first full-scale R&D complexes.

The breadth of the West Orange facility's mandate is one of the first things to strike a visitor. Introducing her sweeping tour, Maryanne Gerbauckas, superintendent of the Edison National Historic Site, explains that it includes a metal foundry, two large machine shops, a fully stocked chemistry lab, a woodworking shop, glassblowing facilities, a darkroom, and sound-recording and film studios, not to mention a lavish, wood-paneled 40,000-volume library. "Edison didn't leave much out in his conception of this place," she says.

To build what he immodestly referred to as the "best equipped and largest Laboratory extant," Edison realized he needed "facilities incomparably superior to any other for rapid and cheap development of an invention . . . into commercial shape." The effort, he noted, would require the facility to carry "a stock of almost every conceivable material," so that he would be able to "build anything from a lady's watch to a locomotive." Israel says the lab reveals that "Edison understood quite early on that naturally occurring materials held open vast possibilities for exploration, exploitation, and development."

Nowhere is Edison's passion for diverse resources as clearly evident as in the storeroom, one of the first stops on Gerbauckas's tour. Standing before banks of small wooden drawers that line several walls, Gerbauckas explains that each holds different samples; to her side larger stocks of metal sheets, rods, and pipes are neatly arranged. She





LARGE PHOTO: THE MACHINE SHOP WHERE EDISON'S ASSOCIATES MADE PROTOTYPES OF HIS INVENTIONS AS WELL AS OTHER NEEDED EQUIPMENT. TOP AND ABOVE: A SAMPLING OF THE INVENTOR'S MATERIALS, INCLUDING ABALONE, ELEPHANT HIDE, AND ASSORTED METAL RODS; AND MALLETS MADE IN THE MACHINE SHOP. LEFT: SOME OF THE NUMEROUS HORNS EDISON PRODUCED IN THE TRIAL-AND-ERROR PROCESS OF CREATING THE FIRST PHONOGRAPH.

recounts the inventor's famous quip that the storehouse contained "everything from an elephant's hide to the eyeballs of a United States Senator."

An 1887 newspaper report confirms that the West Orange stock room contained "eight thousand kinds of chemicals, every kind of screw made, every size of needle, every kind of cord or wire, hair of humans, horses, hogs, cows, rabbits, goats, minx, camels, . . . silk in every texture, cocoons, various kinds of hoofs, sharks' teeth, deer horns, tortoise shell, . . . cork, resin, varnish and oil, ostrich feathers, a peacock's tail, jet, amber, rubber, all ores, [and] metals."

Edison put such exotic substances to use with surprising regularity. His notebooks, for instance, show that in their quest to discover an effective lightbulb filament, he and his assistants experimented with no fewer than 3,000 separate materials, including platinum and Japanese bamboo, before finally settling on carbonized cotton thread. After much similar trial and error, Edison employed compressed rainforest nuts to make the needle used in some of his earliest phonograph models before ultimately choosing tungsten as the best material for the job.

As W. Bernard Carlson, a historian of technology at the University of Virginia, explains it, Edison approached the process of invention more like a craft worker than a theoretical scientist. "For Edison the craftsman, invention was a tactile and visual activity," he says, and "scientific instruments were extensions of his senses." He contrasts the "collection of craft shops" at the West Orange facility, which employed glassblowers and machinists, with the more theoretical approach to conceiving new products that became common during ensuing decades. Of course, Edison also hired mathematicians and scientists throughout his career. But he relentlessly chided his college-educated colleagues that their university experience had corrupted them by teaching them to see only "that which they were taught to look for," thus prompting them to overlook many of nature's great secrets.

Edison persistently held that invention involves not just research but development and marketing—a view that would usher in a new relationship between scientists and the entrepreneurial use of their work.

Tying "R" to "D"

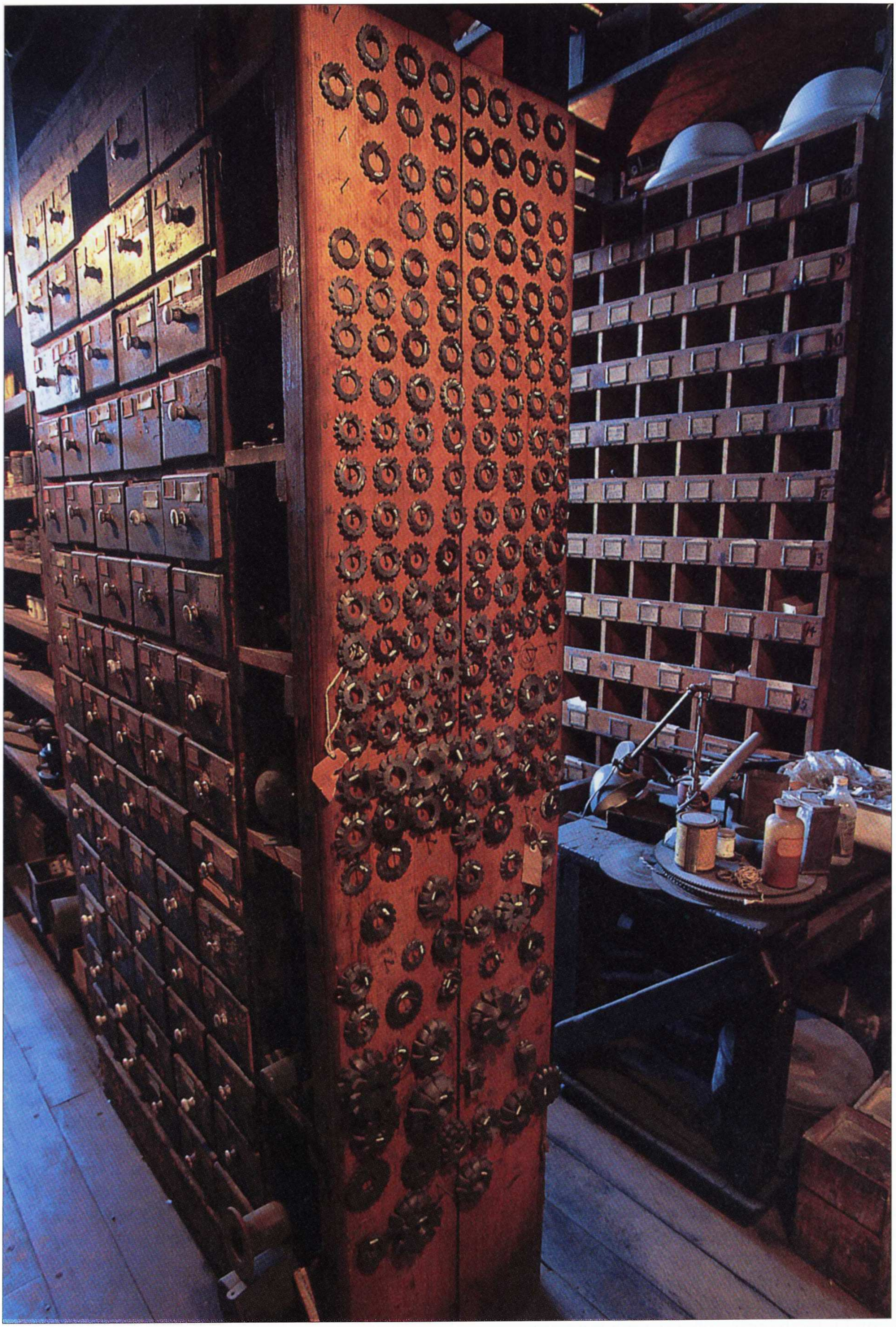
Gregory Field, a historian at the University of Michigan at Dearborn who spent five years scrutinizing the early notebooks as part of the Edison Papers Project, says Edison's key contribution to modern research efforts is his maverick insistence on "always tying the 'R' to the 'D'." Edison persistently held that "invention involves not just research but research, development, and marketing," Field maintains—a view that would ultimately help usher in a new relationship between scientists and the entrepreneurial use of their work. According to Edison, in fact, "Dollars and science were so much mixed up" in his career that it was sometimes hard to separate his inventive activities from the continual stream of commercial ventures in which he involved himself.

To be sure, entrepreneurs of all stripes flourished during Edison's day, and Edison counted some, like Henry Ford and Harvey Firestone, among his close acquaintances. But Edison's approach contrasts with that of many other scientists of his time, including Louis Pasteur of France. Pasteur was well known for his widely accepted view that "a man of science [sic] would complicate his life and risk paralyzing his inventive faculties" if he deigned to involve himself in using his discoveries as a source of commercial profit.

Edison almost defiantly emphasized his role as an "industrial scientist" to contrast himself with academic scientists such as Pasteur. Not surprisingly given his success, he inspired others to pursue a similar approach. For instance, historians have traced Alexander Graham Bell's establishment of a small general research laboratory—the precursor of what would ultimately grow into the enormous Bell Laboratory complex (now Lucent Technologies)—to Edison's example.

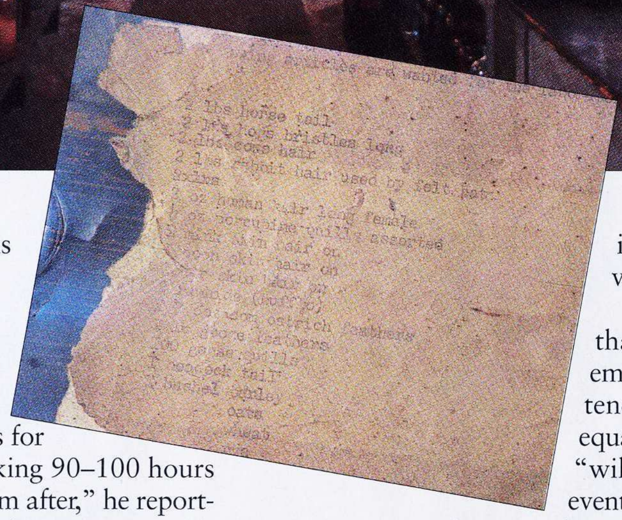
Yet unlike many of the R&D efforts he spawned, Edison repeatedly refused to be closely linked to any particular corporate mission. For example, although Edison relied on sponsors such as Western Union, one of the largest companies of the day, he avoided direct oversight of his work in order to pursue the widest possible R&D agenda.

Edison's independence would prove to be a short-lived "golden moment" in modern research. As early as 1896, Carlson notes, emerging giant General Electric chose to contract with Edison's more systematically oriented competitor Elihu Thompson to attempt to manufacture x-ray tubes. Given that he had worked on such tubes and helped found General Electric, Carlson says, Edison would have been a more obvious choice. "But by then he was already viewed by corporate managers as an unreliable and unpredictable source of innovation," Carlson maintains, because



THE FLOOR-TO-CEILING DRAWERS FULL OF GEARS, NUTS, BOLTS, AND OTHER PARTS
EDISON ASSEMBLED FOR USE IN THE MACHINE SHOP.

EDISON'S WELL-STOCKED CHEMISTRY LAB AND ONE OF HIS SHOPPING LISTS OF WISHED-FOR MATERIALS.



of his insistence on following where his own intuition led.

A Knowledge-Centered Approach

Indeed, of his many colorful attributes, Edison is probably most famous for maniacal persistence, frequently working 90–100 hours per week. "I never quit 'til I get what I'm after," he reportedly answered when asked the key to his success, a variation on his famous maxim that "genius is 1 percent inspiration and 99 percent perspiration."

Nowhere is Edison's tireless persistence as evident today as in a rarely viewed attic closet at the West Orange facility. Walking past rows of shelves holding uncatalogued artifacts on the main building's top floor, Gerbauckas opens the closet door to reveal a staggering display. Here, on shelves and floor, stand scores of phonograph horns of every size and shape. Some are round, others angular; some are short and squat while others are elongated, standing as much as six feet tall. This rogues' gallery of rejected prototypes offers a rich visual testament to Edison's approach: to try out every design he could conceive of.

Extremely hard of hearing, Edison was often frustrated upon not getting loud enough or clear enough sound from his phonograph machine. Edison's archivists have found, Gerbauckas recounts, that the inventor would sometimes even clamp his teeth onto a phonograph horn as a hearing aid, feeling the sound vibrate through his jaw.

Yet the archives reveal that the conventional emphasis on Edison's persistence has overshadowed an equally important attribute: a "wild enthusiasm" for any events out of the ordinary. This openness to new inputs and associations would often elude modern laboratories that attempted to build on Edison's approach.

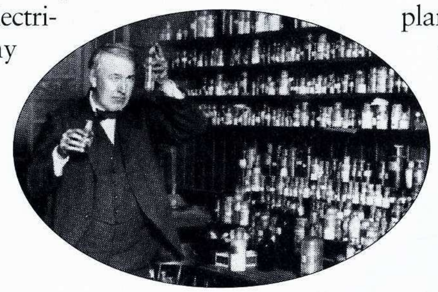
His openness was reflected in his ability to quickly capitalize on emerging scientific knowledge. Rather than wrestle with advancing scientific theory himself, he would comb the published literature for ideas that sparked his interest. This strategy, coupled with independence from corporate hierarchy, gave Edison extraordinary flexibility to regularly reinvent and reconfigure his laboratory.

Carlson notes that "the lab's arrangement was in constant flux," with Edison often redirecting efforts at its various branches and rearranging their thin, non-load-bearing wooden walls to accommodate the new ventures. On one occasion late in 1900, for example, when it was clear that an iron-ore mining venture in which Edison had invested both financial and technical resources was failing, he returned to the West Orange lab on a weekend, cleared out a room in the main building, and laid out a detailed plan to

PHOTO, OPPOSITE PAGE: BETTMAN ARCHIVE

completely redirect the team's efforts toward the manufacture of Portland cement, which could capitalize on some of the same equipment and materials.

Israel reports that he has uncovered new evidence of Edison's enormous talent for appropriating techniques that may have failed in one instance and using them to great effect in another. For example, Edison's unsuccessful work to develop an undersea telegraph cable ultimately led to a breakthrough on a telephone transmitter. In repeated attempts to maintain a constant level of electrical resistance in a prototype of a lengthy transatlantic cable, Edison simply couldn't solve the problem. Many months later, in his work on the telephone, Edison used the principle of variable resistance to help design a telephone transmitter that adapted to the changing soundwaves of a caller's voice—a technique that would serve as the industry standard for the better part of a century.



"The further we get into examining Edison's papers," Israel says, "the more cross-fertilization we recognize, with favored techniques and conceptual models transferred from one problem to the next." While all modern R&D efforts must struggle to balance creative freedom with practical goals, it increasingly appears that Edison's success owes much to the freewheeling, flexible framework in which his highly directed efforts thrived.

Edison relentlessly chided his college-educated colleagues that their schooling had led them to see only "that which they were taught to look for."

Preserving the Legacy

Despite the rich technological heritage embodied in the Edison National Historic Site and the many mysteries of the inventor's work still to be plumbed, a visitor cannot help but be struck by the facility's shabby condition. The damage and deterioration is severe enough, in fact, that the nonprofit National Trust for Historic Preservation cited the lab in 1993 as one of the country's "most endangered historic properties." Touring the main building, for instance, Gerbauckas departs from her largely upbeat, historically oriented remarks to note water damage from a large leak in the roof. An arm's length away, scores of open shelves hold all manner of Edison artifacts, including motors, hand tools, metal castings, architectural models, and gizmos of every description. Just two years ago, a researcher working in the area stumbled upon one of the world's first phonograph recordings buried on one of these shelves. "There may well be more hidden gems here," Gerbauckas says resignedly. "We just won't know for sure until we are able to work our way through it all." A new roof for the main building, she explains, is just one of many costly renovations needed at the site.

To combat such problems, Gerbauckas has helped launch a newly unveiled public-private partnership to restore the aging facility. In an effort the entrepreneurial inventor would undoubtedly have approved of, the new nonprofit Edison Preservation Foundation will solicit private contributions to help maintain the lab complex and Edison archive. The inauguration of the partnership drew a recent visit from Secretary of the Interior Bruce Babbitt, who as titular head of the Park Service hailed the plan as "a prototype" for defraying maintenance outlays throughout the underfunded park system. To be sure, a gaping shortfall remains despite the initial $1 million raised by the trust: the site's renovation is now estimated to cost $60 million. But the partnership plan at least offers a viable structure within which to complete the task.

To encourage broad interest in the new partnership, as well as to commemorate the inventor's 150th birthday, Gerbauckas, DeGraaf, and others working at the site are attempting to open the Edison collection to a wider audience. This spring the Edison archivists will launch a Web site that will ultimately include a fully searchable database of the papers. And DeGraaf is organizing a symposium that will be the first to draw a group of scholars from around the world to consider Edison from every angle: as scientist, entrepreneur, and cultural icon.

Back at the archive office, though, it is business as usual as Thomas Jeffrey, associate director of the Edison Papers Project, plows ahead in the seemingly Sisyphean task of preserving the rich cache of materials for posterity. Jeffrey calculates that the Edison papers if stacked would stand roughly as high as the Chicago Sears Tower. Although he has already spent 17 years attempting to catalogue the collection, Jeffrey estimates that his dedicated team of editors, digging their way through this mountain of paper, will need at least 17 more years to publish a representative sample of the inventor's work on microfilm and in 15 to 20 printed volumes. "When you think that only 3 volumes have appeared so far," he adds, "even 2015 may prove to be an optimistic deadline."

Jeffrey is candid in his assessment of the consequences of this slow process: "So far," he says, "most scholars have been able to study only the tip of the iceberg of this collection. And there is no question that piecemeal access to the material has limited the range of scholarship." But someday, he says, "the intellectual resources hidden away at this site will be unlocked. We are creating an essential roadmap into this invaluable collection." ■

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Painting the Town

Urban heat islands are not inevitable, but the product of dark roofs, black pavement, and loss of vegetation. A "cool communities" approach would lower air-conditioning use and make the air healthier.

BY

ARTHUR H. ROSENFELD

JOSEPH J. ROMM

HASHEM AKBARI

AND

ALAN C. LLOYD

ILLUSTRATION BY STUDIO Q

White—and Green

Trees not only shade individual buildings but also cool the surrounding air by drawing water from the ground and evaporating it from their leaves.

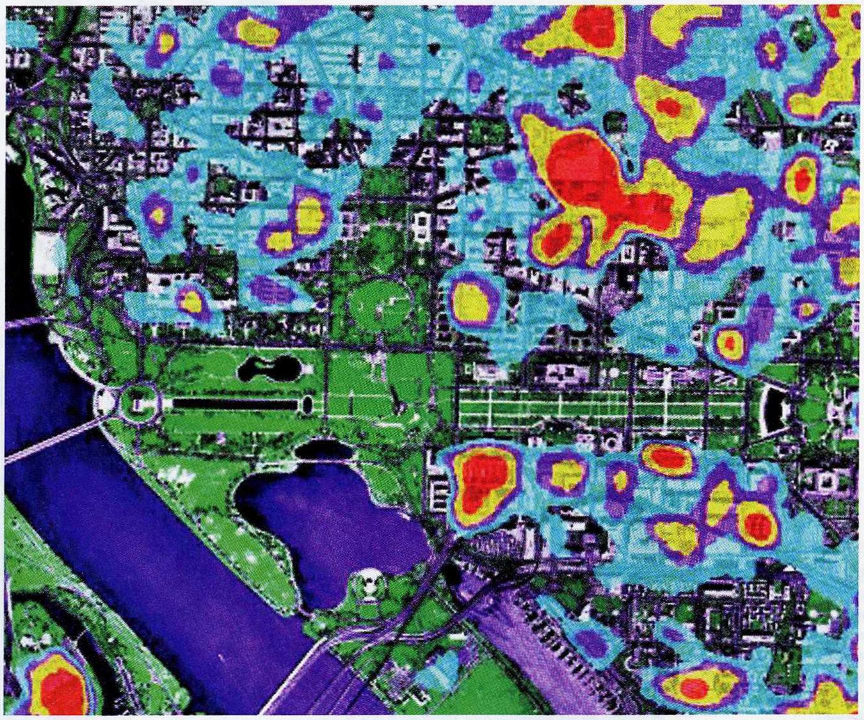
On a summer afternoon, central Los Angeles registers temperatures typically 5° F higher than the surrounding suburban and rural areas. Hot roofs and pavements, baked by the sun, warm the air blowing over them. The resulting urban "heat island" causes discomfort, hikes air-conditioning bills, and accelerates the formation of smog.

Heat islands are found in many large cities, including Chicago, Washington, and (as the Olympic athletes and fans can attest) Atlanta. The effect is particularly well recognized in cities that quote two airport temperatures on the weather report. Thus Chicago-Midway airport is typically a few degrees hotter than suburban O'Hare, and the same difference applies between Washington National airport and Dulles.

Contrary to popular opinion, heat islands do not arise mainly from heat leaking out of cars, buildings, and factories. In summertime, such anthropogenic heat gain accounts for a mere 1 percent of the heat island's excess temperature. (The fraction rises in the winter to about 10 percent, when heat does leak out of buildings.) Rather, dark horizontal surfaces absorb most of the sunlight falling on them. Consequently, dark surfaces run hotter than light ones. The choice of dark colors has caused the problem; we propose that wiser choices can reverse it.

We are now paying dearly for this extra heat. One sixth of the electricity consumed in the United States goes to cool buildings, at an annual power cost of $40 billion. Moreover, a 5° F heat island greatly raises the rate at which pollutants—nitrogen oxides and volatile organic compounds emanating from cars and smokestacks —"cook" into ozone, a highly oxidizing and irritating gas that is the main ingredient of smog. In Los Angeles, for example, ozone rises from an acceptable concentration at 70° F to unacceptable at 90° F. The Los Angeles heat island raises ozone levels 10–15 percent and contributes to millions of dollars in medical expenses. (In winter, we have plenty of smog precursors but, because it is cool, little smog.)

Fortunately, we can go a long way toward dissipating urban heat islands with modest measures. One solution is to use lighter colors for roofs and pavement. The other is to plant lots of trees, which have a twofold benefit. First, they provide cooling shade. Second, trees, like most plants, soak up groundwater. The water then "evapotranspires" from the leaves, thus cooling the leaves and, indirectly, the surrounding air. A single properly watered tree can "evapotranspirate" 40 gallons of water in a day—offsetting the heat equivalent to that produced by one hundred 100-watt lamps, burning eight hours per day.



HOT SPOTS IN WASHINGTON SHOW UP AS RED AREAS IN THIS SATELLITE IMAGE. THE PRESENCE OF SUCH HEAT ISLANDS INCREASES ENERGY USE AND RAISES SMOG LEVELS. THE LARGEST RED PATCH IS AT THE SITE OF A CONVENTION CENTER. THE COOLEST AREAS (GREEN) ARE THOSE COVERED BY GRASS AND TREES.

Increases in temperature do not have to follow from an influx of population. The Los Angeles basin in 1880 was still relatively barren, and yearly highs ran about 102° F. Then settlers introduced irrigation, the fruit trees cooled the air, and, within 50 years, summer temperatures dropped 5° F. But as Los Angeles began to urbanize in the 1940s, cool orchards gave way to hot roofs and asphalt pavements. Over the next 50 years, summer highs climbed back to their 1880 values—and are still

ARTHUR H. ROSENFELD is senior adviser, and JOSEPH J. ROMM is principal deputy assistant secretary for energy efficiency and renewable energy, at the U.S. Department of Energy. ALAN C. LLOYD, former chief scientist for California's South Coast Air Quality Management District, is director of the Energy and Environmental Engineering Center at the Desert Research Institute in Reno, Nev. HASHEM AKBARI is principal investigator of the heat islands project at DOE's Lawrence Berkeley Laboratory.

rising at 1° F per decade, with no end in sight.

But with white roofs, concrete-colored pavements, and about 10 million new shade trees, Los Angeles could be cooler than the semidesert that surrounds it, instead of hotter. Such measures would be in keeping with approaches that have been taken for centuries. As civilization developed in warm climates, humans learned to whitewash their dwellings. Even today, building owners in hot cities like Haifa and Tel Aviv are required to whitewash their roofs each spring, after the rains stop.

In the United States, dwellings tended to be built with white roofs through the 1960s. Then, as air conditioning became widespread, cheap, and taken for granted, priorities shifted. It became popular to use darker roofing shingles, which more resembled wooden shingles and better concealed dirt and mold. The colored granules on typical "white" shingles made today are coated with only one-sixth as much white pigment as in the 1960s. Under the summer sun, modern shingles become 20° F hotter than the old-style ones.

In devising our "cool communities" strategy, we have focused our attention on helping Los Angeles—the smog capital of the United States—though its elements could be applied in other cities as well. Computer modeling of Los Angeles' heat island bears out what Mediterranean architects have known for thousands of years. Together, the planting of trees and the lightening of roofs and pavement could lower the average summer afternoon temperature in the Los Angeles heat island by 5° F, cutting the need for air conditioning by 18 percent and significantly lowering the levels of smog.

Simulating a Cooler LA

Urbanized Los Angeles covers 10,000 square kilometers and includes about 1,250 square kilometers of roof and another 1,250 square kilometers of pavement. Obviously, we cannot instantly replace these with cooler-colored materials. Nor can we quickly plant the 10 million shade trees that would make a difference. We can, however, simulate these actions using computer models. In our own simulation, we raise the city albedo—the reflected fraction of incident solar heat—by a modest 7.5 percent and cover 5 percent of its area with 10 million trees.

The models indicate that our "cool community" strategy has a lucrative benefit/cost ratio. The use of white roofs and shade trees in Los Angeles would lower the need for air conditioning by 18 percent, or 1.04 billion kilowatt-hours, for the buildings directly affected by the roofs and shaded by the trees. If we assume a price of peak electricity of 10 cents per kilowatt-hour—not uncommon—this translates into savings of $100 million per year.

Because white shingles show discoloration by fungus, the manufacturer must add fungicide, raising the cost. The difference, however, is not large. For a 1,000-square-foot roof, the cost premium of cooler shingles is less than $25. If lighter tiles raise the albedo 35 percentage points, the additional investment pays for itself in less than one summer's worth of lowered air-conditioning bills.

There is also a large indirect benefit. If an entire community drops a degree or so in temperature, thanks to lighter roofs and pavement and to the evapotranspiration from trees, then everyone's air-conditioning load goes down—even those buildings that are not directly shaded or that still have dark roofs. This indirect annual savings would total an additional 12 percent—0.7 billion kilowatt-hours, or $70 million. As shown in the table below, implementing

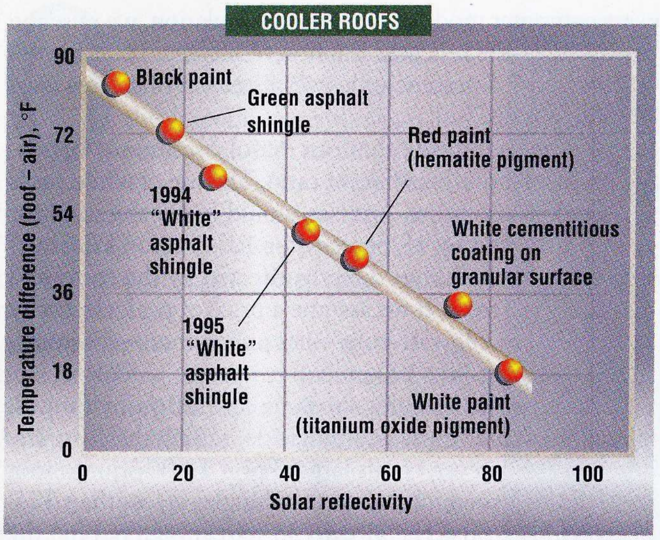
BENEFITS TO LOS ANGELES OF "COOL COMMUNITIES" MEASURES

	DIRECT ENERGY SAVINGS		INDIRECT ENERGY SAVINGS		SMOG BENEFIT	TOTALS	
	Avoided peak power (MW)	A/C cost savings ($M/yr)	Avoided peak power (MW)	A/C cost savings ($M/yr)	Avoided medical costs, 12% ozone reduction ($M/yr)	Total avoided peak power (MW)	Total cost savings ($M/yr)
COOLER ROOFS	400	46	200	21	104	600	171
TREES	600	58	300	35	180	900	273
COOLER PAVEMENT	0	0	100	15	76	100	91
TOTAL	1000	104	600	71	360	1,600	535

TREES AND LIGHTER-COLORED ROOFING MATERIALS COULD SAVE ENERGY AND CLEAN THE AIR, COMPUTER MODELS SHOW. "DIRECT" SAVINGS REFER TO THE COOLING EFFECT ON INDIVIDUAL BUILDINGS. "INDIRECT" SAVINGS REFER TO THE CUTS IN AIR CONDITIONING LOAD FOR ALL BUILDINGS AS THE TEMPERATURE OF THE SURROUNDING COMMUNITY DROPS. THE FIGURES ASSUME THE PLANTING OF 10 MILLION NEW TREES AND THE LIGHTENING OF 2,500 SQUARE KILOMETERS OF ROOFS AND PAVEMENT.

PHOTO: BILL WEEMS/WOODFIN CAMP & ASSOCIATES

Home builders in the U.S. favor dark shingles because they don't show dirt. Better-informed consumers may come to regard these dark surfaces as ugly thermal polluters.



these cool community measures would lower the need for peak electrical generating capacity by about 1,500 megawatts—equivalent to two or three large power plants.

The cooler temperature would lower smog, too. Smog "exceedance"—the amount by which ozone levels top the California standard of 90 parts per billion—would drop 12 percent. Ozone can irritate the eyes, inflame the lungs, trigger asthma attacks, and lower the respiratory system's ability to fight off infection. While other components of air pollution also exact a toll on health—especially particulates and sulfur dioxide—ozone is figured to be responsible for about $3 billion in health-related costs every year in the Los Angeles basin. Thus a 12 percent reduction in ozone exceedance could save $360 million.

The benefits of light surfaces and shade trees extend beyond Los Angeles. The 18 percent direct savings of air conditioning attained by shading and lightening individual buildings do not depend on the size of the city, only on its climate; Atlanta, for example, would enjoy the same percentage reduction as Los Angeles. The indirect savings, on the other hand, will be significant only in large cities with significant heat islands. Since about half the U.S. population lives in heat islands, we estimate that the annual direct plus indirect U.S. energy savings, after 20 years, might be 20 percent. Peak air-conditioning demand would probably drop by 10 percent.

ABOVE: LIGHTER-COLORED SHINGLES SIGNIFICANTLY LOWER A ROOF'S TEMPERATURE. RED-PAINTED TILES ARE COOLER THAN WHITE ASPHALT BECAUSE THE SEEMINGLY DARKER SURFACE ACTUALLY REFLECTS INFRARED BETTER.

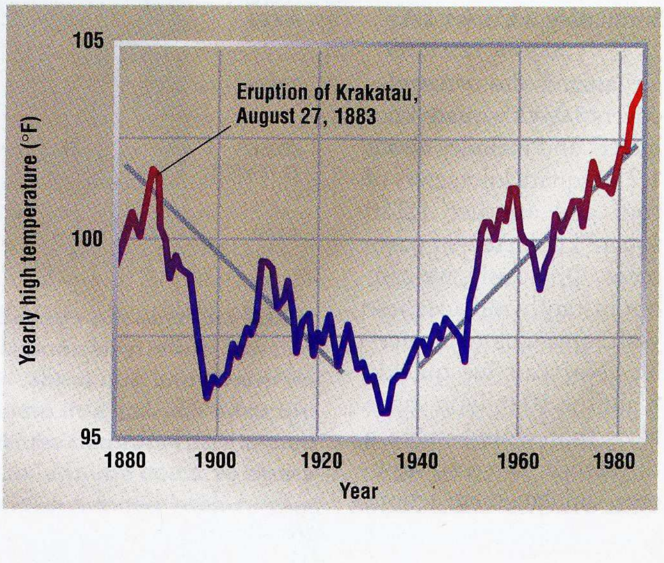
BELOW: LOS ANGELES COOLED AS SETTLERS IRRIGATED THE DESERT AND PLANTED TREES (COOLING WAS TEMPORARILY ACCELERATED BY KRAKATAU'S SUN-COVERING ASH). BUT AS ORCHARDS GAVE WAY TO HOT ROOFS AND PAVEMENTS, TEMPERATURES HAVE CLIMBED BACK TO THEIR 1880 VALUES.

A Tree (x 10 million) Grows in Los Angeles

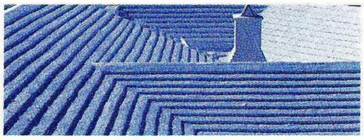
One of our remedies for urban heat islands has an even greater benefit. Most policymakers and environmental activists concerned with the threat of global warming urge two strategies to combat it: cutting the use of fossil fuels; and planting trees, which sequester carbon dioxide in their wood. The planting of trees in cities does both of these, and is far more effective than planting trees in forests.

Any tree—whether in the forest or the city—removes CO_2 from the air through photosynthesis. Typically, a tree sequesters a few kilograms of carbon per year in its wood. For a forest tree, that is the total benefit of the tree's existence, from the standpoint of cutting CO_2 levels. But a tree planted in a city also lowers fossil fuel usage, by cooling the city and thus reducing the amount of electricity consumed in air conditioning. A tree in Los Angeles, for example, will save an additional 3 kilograms of carbon per year by lowering the city's overall need for air conditioning, plus 15 kilograms more if it directly shades a building.

Thus, present efforts by organizations concerned with greenhouse warming to plant trees in forests ought to be broadened to stimulate utilities in cities with growing air-conditioning demand to start shade-tree/cool-surfaces programs. Such programs would not only save more CO_2 per tree than would forest trees, but would mitigate smog problems as well. A massive tree-planting campaign would be compatible with Southern California's present water supply. Los Angeles gets enough rain to support trees without irri-



DIAGRAMS: MICHAEL PRENDERGAST



gation (except for their first few years). A tree shading a lawn actually saves municipal water, which would otherwise go to watering the lawn.

Not all trees are equally beneficial. It is better to plant deciduous trees, for example, which give shade in summer but do not block the warmth in winter. Also, some types of trees emit large amounts of the volatile organic hydrocarbons (VOCs) that combine with oxides of nitrogen to form smog. Ash and maple are among the more VOC-free trees, emitting only about 1 VOC unit (defined as one microgram per hour per gram of dry leaf). Eucalyptus trees, on the other hand, are a problem. They were introduced a century ago, are thriving, and emit 32 units; perhaps they should be replaced with more suitable native trees. Weeping willows top the emissions list, releasing a whopping 230 VOC units.

Getting There

We've shown that cool communities measures in Los Angeles could reduce air-conditioning bills by $175 million per year and alleviate $360 million per year of smog-related expenses. How will we get to this happy point?

Part of the solution will be up to the roofing industry. We are working with roofing manufacturers to develop a new generation of cooler shingles and tiles. They will most likely contain a coating of titanium dioxide (TiO_2) to provide an attractive light color. Because white surfaces are easily discolored by fungus, these shingles will also need to have a fungicide coating. When fabricated with a smooth surface, these shingles will self-wash and thus stay cool for their entire service lives. The increase in albedo of such shingles can be more than the 35 percentage points assumed in our simulations. (The coolness of a material cannot always be discerned from its apparent lightness. In tests, we have found that "cool" terra-cotta tiles run 6°F cooler than "white" asphalt-fiberglass shingles. The reason: half the heat from the sun arrives as invisible radiation in the near-infrared part of the spectrum, to which architects and roofers have paid little attention. Fortunately, TiO_2 reflects well in the infrared. So one can make a cool pastel shingle by adding a little light color to a modern cool white TiO_2 shingle.)

Another contributor to the heat island effect is pavement. Asphalt pavement is, by volume, about seven-eighths rock aggregate, cemented together with one-eighth sticky black asphalt. Over a few months, asphalt wears close to the color of the aggregate. By choosing lighter aggregate, we estimate that we can triple the solar reflectivity of worn asphalt pavement. Unfortunately, although there are thousands of pages of specification of the properties of aggregate from quarries and rivers, nobody has thought to list its color. Thus no one

The Winter Penalty

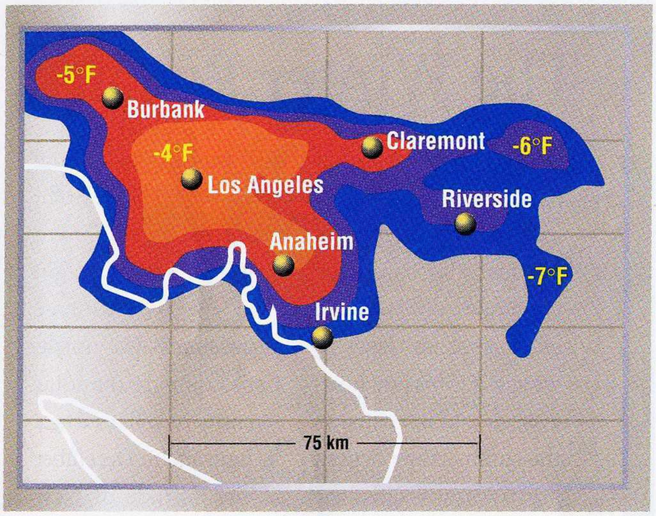
THE same steps that make buildings easier to cool in summer also can make them more difficult (and expensive) to heat in winter. It turns out, however, that in hot climates the summertime benefit greatly outweighs the wintertime penalty. That's because in summer the sun is high overhead and shines mainly on the roof of a home; in winter the low sun shines on the walls and through the windows. So if we want a home to stay cool in the summer, we want it to have a light-colored roof. But to *capture* solar heat in the winter, the roof plays less of a role; it is more important to have large south-facing windows.

For example, in a climate like that of the inland parts of Los Angeles (say, the San Fernando Valley), a homeowner will pay about $40 less for a season's worth of air conditioning if the roof is white rather than green. But the winter heat bill for the white-roofed home will be only $10 more than for the green-roofed home, for a net savings of $30.

White roofs retain their energy advantage surprisingly far north. Let's compare the solar intensity on a flat surface in June and in December at the latitude of New York City. By December, the length of the day has halved, and the sun is so low that it "sees" only half the roof area that it saw from on high in June. Moreover, New York is about three times cloudier in winter than summer. The three factors multiply: 1/2 x 1/2 x 1/3 = 1/12, so potential solar absorption on a roof is only 1/12 as great in December as in June. The bottom line: because so little winter sunlight ever makes it to the roof in the first place, it doesn't much matter what color it is. White shingles therefore make buildings much cooler in summer and yet only slightly colder in winter, because only a relatively small amount of absorbed sunlight is foregone.■

PHOTO: MIKE YAMASHITA/WOODFINN CAMP & ASSOCIATES

The cooling of Los Angeles by 5°F would take about 15 years as newly planted trees grew larger, and roofing and pavement were replaced as part of normal maintenance.



ABOVE: USE OF LIGHTER-COLORED ROOFS AND PAVEMENT WOULD COOL THE LOS ANGELES BASIN SIGNIFICANTLY. FIGURES INDICATE THE PREDICTED EFFECT ON NOONTIME TEMPERATURES, IF ALBEDO—THE AMOUNT OF REFLECTED SUNLIGHT—RISES BY 13 PERCENT.

BELOW: OZONE CONCENTRATION IN LA RISES DAILY AS THE CITY WARMS UP, TYPICALLY EXCEEDING SAFE LEVELS BY AFTERNOON. THE LOWER CURVE SHOWS THE PREDICTED CHANGE IN OZONE IF TREES ARE PLANTED NEAR BUILDINGS AND LIGHT ROOFS REPLACE DARK ONES.

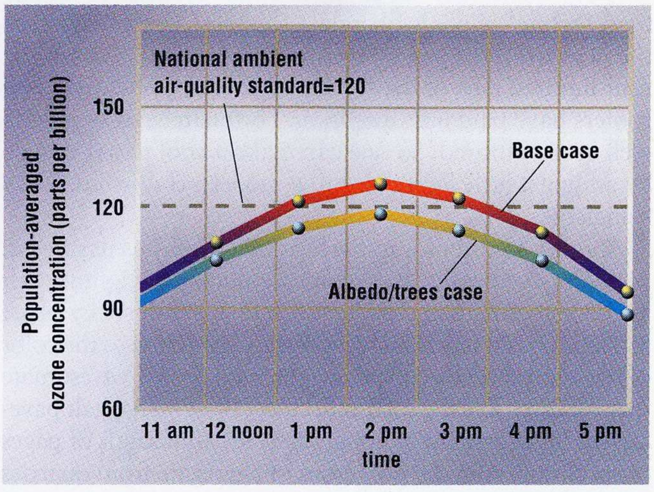
knows if there will be a significant cost premium for lighter aggregate.

Even without such knowledge, we should at least urge asphalt resurfacing contractors to discontinue the now common practice of "topping off" their work with black asphalt and carbon black. Better yet would be to switch the binder from asphalt to lighter-colored Portland cement. Although its first cost is higher than asphalt, cement is stronger and lasts longer, so its life-cycle cost is lower. Iowa already requires cement roads as a long-term cost-savings policy.

Local utility companies also can play a big role. Southern California Edison (SCE), which serves two-thirds of the Los Angeles basin, could offer incentives for its customers to plant shade trees and install cool roofs, thus reducing air-conditioning needs. Thanks to California's efficiency-minded utility regulations, SCE can reap a substantial profit from this lessening of demand. A utility implementing a conservation program that saves its customers money is permitted to raise its rates slightly, so that the savings is shared with the stockholders. Of the roughly $100 million a year that white roofs and shade trees could save in air-conditioning expenses in SCE's territory, for example, $70 million might go to the utility's customers and $30 million to its stockholders.

Because cool communities lower smog, some of the impetus should come from the agencies responsible for managing air pollution. In Los Angeles, that means the South Coast Air Quality Management District, or SCAQMD. Fortunately, SCAQMD took a prudent step in 1994 by capping total NOx emissions from the region's industries, and lowering the cap 8 percent each year. To give businesses flexibility in reducing emissions, SCAQMD started the Regional Clean Air Incentive Market (RECLAIM). Under RECLAIM, companies in compliance with the cap can sell their excess emission-reduction credits to companies that are out of compliance. As in any market, the price of NOx credits is determined by supply and demand.

When RECLAIM started in 1994, it traded only NOx. But the program is now judged a success and is being extended to the other main smog ingredient: VOCs. RECLAIM is also considering giving "cooling credits" for measures that slow the formation of smog from NOx and VOCs. Anything that lowers the temperature of the air would count. The Environmental Protection Administration has urged RECLAIM to adopt these "cooling credits." If this happens, the Los Angeles roofing contractors association could sell cooling credits on behalf of its members, who would in turn promote cooler roofs and could afford to offer rebates to their customers. An asphalt pavement association could do the same for roads and parking lots. Landscaping contractors could sell credits for trees and other vegetation. Regional air pollution markets like RECLAIM are spreading beyond Los Angeles. Chicago is close to developing one, and a consortium of northeastern states is aiming for 1999. A number of other states have such programs on the drawing boards.



The federal government has a role to play as well. Thus we at the Department of Energy, working with the Environmental Protection Agency, will introduce two sorts of labels. One will be a quantitative "solar reflectance index" that should appear on all roofing material. This will resemble the familiar yellow EnergyGuide labels on all appliances. The other will be called Energy Star. It will adorn only the coolest one-third of the products on the market, and will resemble Energy Star labels already on computers and other efficient products. Over time, better-informed consumers may come to regard hot surfaces as wasteful and ugly thermal polluters.

Los Angeles, or any other large city, cannot be cooled in a day. In fact, the 5° F lowering of the heat-island temperature by the steps we have outlined would take about 15 years. That's because it is economical to install the cooler surfaces only when normal refurbishing is due, and the lifetime of roofs and pavements are on this time scale. Also, trees take about this time to grow fully.

But it will take a lot longer—forever?—unless businesses and policymakers give cool roofs and tree planting the high priority they deserve. California's clean-air strategy makes use of two tactics that promise to yield about the same benefits as cool communities. One is reformulated, cleaner-burning gasoline, which was introduced last summer. The new gasoline reduces smog precursors by about 15 percent. California's other major tactic is to introduce electric cars on a large scale. According to present plans, electric cars are to start at 2 percent of sales in some as-yet-undefined year, and quickly rise to 10 percent of sales. This transition would reduce smog several percent. But as with cool surfaces and trees, there would be a 10- to 15-year delay before the car stock turns over.

The air-pollution benefits of reformulated gasoline and electric cars can be complemented by the planting of trees and installing of lighter-color roofs and roads. These cool-communities strategies not only save energy and clean the air but also yield a more hospitable local climate. ■

PHOTO: BARBARA FILET / TONY STONE WORLDWIDE

BY LARRY BELL

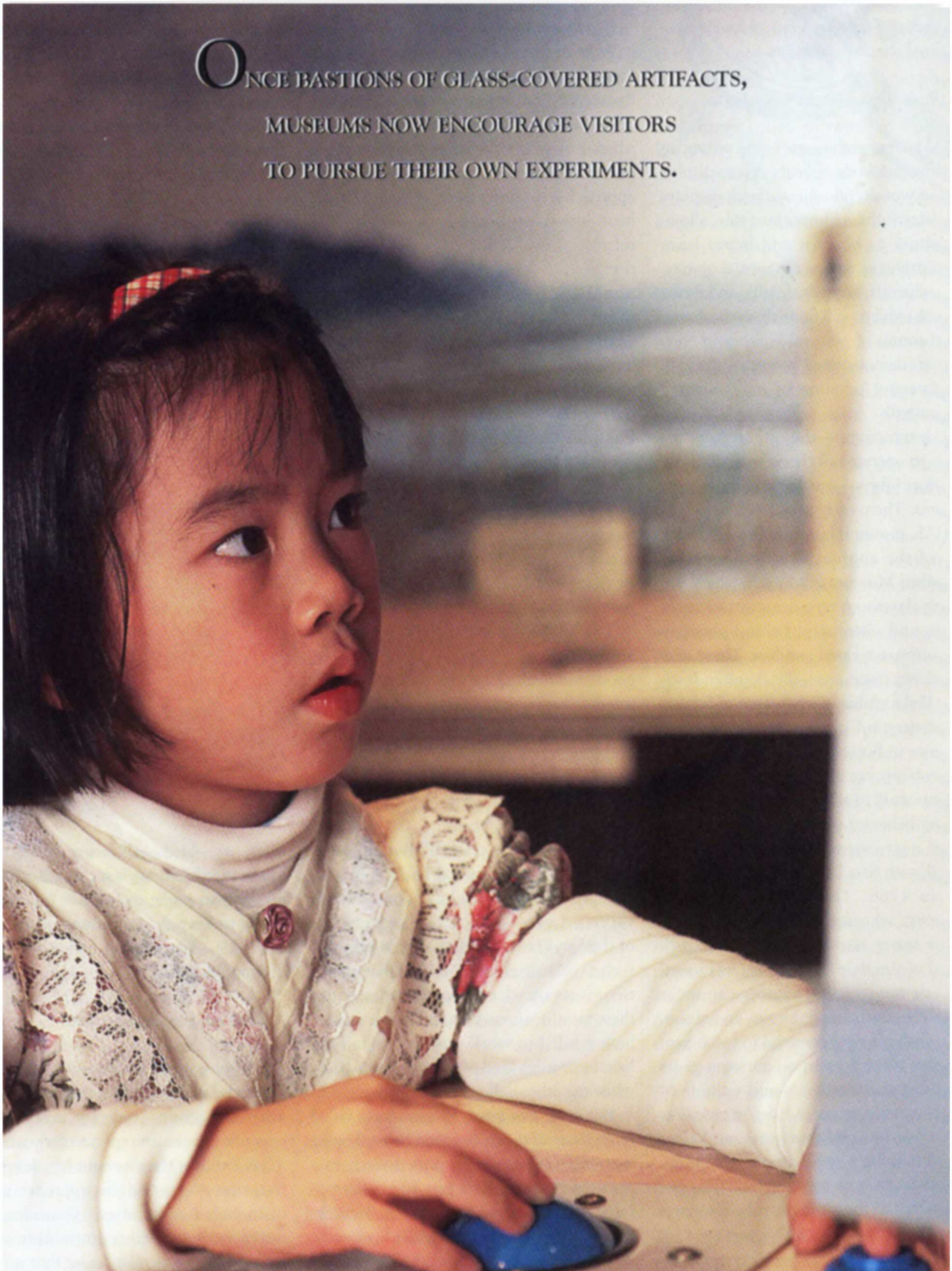
Scientist for a Day

Elbow Grease and Discovery in the New Science Museum

In the solar-car workshop at Boston's Museum of Science, three groups of parents and children are trying out model automobiles they have built. Suddenly everyone rushes back to a workbench to change wheels, adjust the tension on a rubber-band pulley that connects an electric motor to the drive axle, and make other alterations. Meanwhile, another team is attempting to get its refined model to run a test race course in 12 seconds. When it comes close—12.8 seconds—the kids cheer. And in another corner, after 35 minutes of nonstop work to correct a model whose wheels at first spun only when the car was held up in the air, an 11-year-old boy looks around and finds someone he knows. "Come look!" he cries. "I made it work," and explains what he discovered.

The solar-car workshop represents the cutting edge in exhibits at science centers. Across the country, exhibit developers are creating open-ended experiments designed to stimulate in visitors the kinds of thinking scientists employ. These reformers are discounting the traditional notion that museums can teach little

PHOTO ABOVE: BOSTON'S MUSEUM OF SCIENCE



PHOTOGRAPHS ABOVE AND ON FOLLOWING PAGES TAKEN AT BOSTON'S MUSEUM OF SCIENCE
BY FRANK SITEMAN

about the scientific process during a typical brief visit. Developers even maintain that their work can serve as a model for enhancing formal science education.

From Push Buttons to Blended Faces

Natural-history enthusiasts began setting up museums hundreds of years ago to display rare and wonderful objects. Such displays even today fulfill an important role, allowing visitors to observe and hence learn about intriguing aspects of unusual objects: rocks, minerals, animals, fossils, and more. And such exhibits still flourish, as the American Museum of Natural History in New York City demonstrated two years ago with the successful opening of its renovated dinosaur halls.

But interactivity—the opportunity for visitors to operate or otherwise manipulate parts in exhibits—was lacking in the first museums. Then, early in the twentieth century, U.S. museum curators brought back word of the approach of the Deutsches Gesundheit Museum in Munich, which was offering classroom-type demonstrations of physics and chemistry, behind glass, in pushbutton-activated exhibits. Three new U.S. science museums—the Franklin Institute in Philadelphia, the Museum of Science and Industry in Chicago, and the Museum of Science in Boston—introduced not only push buttons but live demonstrations by museum staff to stimulate interest in the ordinary behavior of all kinds of objects.

The next wave in science exhibits arrived with San Francisco's Exploratorium in 1969. This museum's exhibit developers, who were scientists and artists, took a more hands-on approach still. Instead of simply pressing buttons to activate a demonstration, visitors can more intimately control variables in an exhibit. In one such offering designed to teach people about wave properties, museum-goers can adjust the frequency and volume of sound waves produced by a speaker attached at one end to a horizontal glass tube containing a small amount of liquid. Visitors learn how to play with the controls so that as the air in the tube resonates at particular frequencies, liquid drops fly up to reveal standing waves.

By relying on objects that look as if they have been found in, say, a basement, the Exploratorium's developers have also tried to create rough-looking exhibits that suggest working prototypes rather than the finished showpieces displayed by many other science museums. Moreover, the museum's approach is to cluster these items into themes, such as refraction and polarization, with sets of instructions that lead visitors through a series of steps, so that people walk away having gained a logical understanding of some particular phenomenon. For instance, the tube demonstrating standing waves might be located near a machine that mechanically produces a variety of waves, shown by rising and falling ping-pong balls.

The Exploratorium's approach has been so good that it has influenced science museums everywhere, so that almost everyone working in science centers has come to link the word "interactive" with the phrase "educationally successful." But although museums have copied the Exploratorium's approach, they have done so with varying degrees of success. Exact replicas of the San Francisco institution's exhibits, such as a "half-silvered" mirror that allows two visitors, each on opposite sides, to see their facial features blended in one image, have tended to work very well. (Half the light hitting this kind of mirror reflects back, while the other half transmits through.)

But some exhibit developers have failed to understand that interaction best enhances learning if it engages visitors directly in a phenomenon and have too often incorporated gratuitous and hence useless interactivity in new exhibits. Consider how some 20 years ago, developers at the Museum of Science in Boston proposed teaching bird ecology with the aid of a pinball machine—an object popular with children. The idea was to repaint the game surface so that different areas represented survival factors in the life of a bird. But while a pinball game may convey some lessons on mechanics and trajectories, it does not intrinsically teach anything about birds or how scientists learn about birds. The new labels on the machine would have conveyed all the exhibit had to offer on birds—differing little from museum exhibits in glass cases. And clearly no one was going to read the labels while trying to keep the balls from going down the hole. Fortunately, the developers dropped the idea.

Museum developers have recognized that open-ended activities can stimulate visitors to pursue the scientific process on their own.

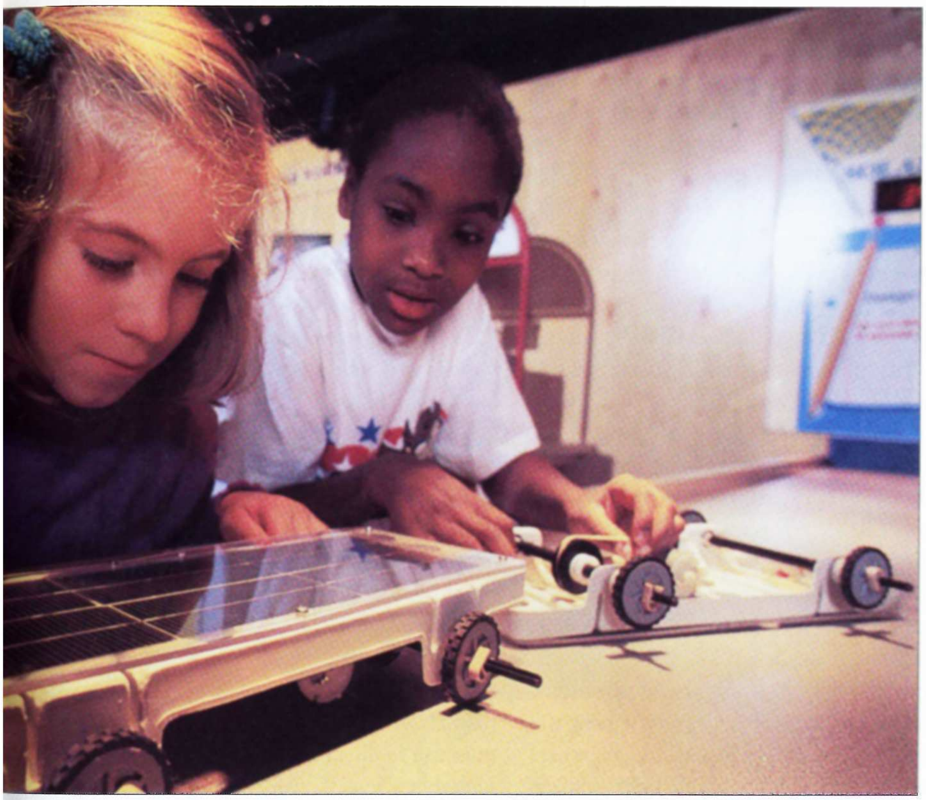
A Twist on Visiting Scientists

The Exploratorium has continued to produce one exhibit after another that uses creative interactions to demonstrate specific scientific phenomena spectacularly well. But a few exhibits the museum has developed over time go beyond this approach to risk open-ended outcomes. Consider, for instance, a table with a central light source embedded in a metal cylinder that is outfitted with slits. Attached to the table by cords are various types of small mirrors and lenses

LARRY BELL is vice-president for exhibits at Boston's Museum of Science, where he has developed and taught courses and demonstrations.

that visitors can experiment with as the light radiates across the table. While such exhibits may not seem as effective in teaching specific content-based lessons, developers elsewhere have recognized that these activities can stimulate visitors to carry out the scientific process on their own, and hence can be quite valuable educationally. Inspired, developers have begun to push the design of such open-ended exhibits further.

There, visitors can explore various topics with a corps of scientist-teachers. The activity of conducting research is what counts. In Science North's "Swap Shop," for instance, people can both bring in and examine others' small displays of natural objects—such as rocks, animal bones, and shells—using apparatus such as microscopes, tools, maps, and charts.



The result has been exhibits that resemble working laboratories, where visitors can pursue their own short research projects and find their own answers to the questions they themselves pose. The thinking is that science is not just about, say, the physical, chemical, or biological attributes of the world around us, but a process for learning about the world. No matter what scientific information visitors may take home, the most valuable lesson an exhibit can convey is that process.

The first museum to make a full-fledged stab at the "do-your-own-research" approach was Science North, which opened in 1984 in Sudbury, Ontario. That museum—or, more properly in this case, that science center—includes interactive areas akin to a scientist's work space.

This approach has sparked widespread excitement among museum developers, and others have started coming up with similar approaches. One of the first to follow up was J. Shipley Newlin, a developer at the Science Museum of Minnesota in St. Paul, whose Experiment Gallery focuses on "experiment benches" where one to three visitors can have exclusive use of apparatus to choose which of many variables to control, devise their own experiments, and hence experience many outcomes.

One of the most successful exhibits is the Electricity Lab, which allows visitors to explore basic electrical components such as resistors, light bulbs, motors, capacitors, diodes, and switches. These click together and can be attached to copper wire to form different kinds of low-voltage circuits. (The circuits are protected so damage does not occur. And to provide more insurance against problems, a staff member stays in the Experiment Gallery.) In a more traditional interactive exhibit, a few components might be bolted to a table, with visitors able to change a couple of variables. But in the Electricity Lab, visitors actually build the circuits and decide what to include.

Evaluations have shown that visitors stay longer at experiment benches than at the museum's more traditional interactive exhibits—as much as 19 versus 6 minutes. But the open-ended nature of the experiment-bench model also creates some problems. With many options available, some visitors have difficulty figuring out what to do. They have said they need better instructions. The Science Museum of Minnesota has dealt with this concern by adding "Experiment Cards" to the labs that suggest tasks with easy, moderate, and challenging levels of difficulty.

Another center that has taken open-ended exhibits to a new level is Portland's Oregon Museum of Science and Industry, which in 1993 opened "Engineer It!"—an exhibit that gives visitors firsthand experience in designing, building, and testing an object such as a model boat or airplane. Budding engineers can select from numerous parts in bins and refer to examples of how they fit together. They can then tether their paper airplanes in the wind tunnel to see if they will fly, modify the design of model trucks and test how much drag they encounter while moving down a "highway," or construct buildings on a table that shakes to see if the design is earthquake-proof.

At this museum, evaluators have found that most visitors pay relatively little attention to the instructions, designing by trial and error instead and learning a great deal from other museum-goers by mimicking their designs and making improvements to objects left behind. In so doing, visitors behave like scientists, who similarly build on one another's results through personal contacts as well as published papers.

Boston's "Activity Centers"

The largest-scale effort to develop exhibits that focus on scientific-thinking skills—a series of six "activity centers"—is under way at the Museum of Science in Boston,

the institution where I work. This past March we inaugurated the activity center "Investigate! A See-for-Yourself Exhibit." This center focuses on skills associated with conducting an experiment: asking questions, formulating hypotheses, planning and carrying out a procedure, collecting data, analyzing evidence, and drawing conclusions. At the entrance, visitors encounter a sculpture of a girl standing atop a stack of bedroom furniture, just as she's about to drop a softball and a golf ball to see which will hit the ground first. This evocation of Galileo's apocryphal Tower of Pisa experiment symbolizes the exhibit: conducting experiments on one's own.

Behind the sculpture is a wall of questions and a room devoted to the first step in conducting an experiment—asking a question that can be answered. This room, intended to encourage reflection, contains intriguing objects identified with questions rather than answers: "What is it made of?" "What could you use it for?" "Where did it come from?" "Was it once alive?" Visitors can add their own questions to the wall or their thoughts about the objects by writing these on index cards and posting them for others to see.

From that central room visitors can head in different directions. Those who turn to the right enter a brightly lit room with several experiment stations. Using a wire temperature probe attached by a cable to a computer with a colorful display screen, investigators can measure the temperature of various items as they consider whether, say, Styrofoam keeps a drink hotter than a paper cup does, and how quickly fans blowing on a hot cup cool it. Visitors can also devise experiments involving their skin temperature, such as one to determine whether one person's hand is warmer than another person's. "Challenge Cards" offer some initial ideas for research questions, but the exhibit becomes truly successful when patrons start pursuing inquiries developers didn't consider.

Soon after we opened the exhibit, we noticed one such set of inquiries at the "Drop Stop," which lets visitors recreate the Galileo experiment. They put all sorts of objects in two metal buckets and push a button to transport them 12 feet into the air. Pushing another button makes the buckets open and drop their contents at the same time. A row of sensors connected to a computer tracks the falling objects and indicates their locations at different points in time.

What we didn't expect to generate so much interest is a safety-interlock mechanism that prevents each returning bucket from accidentally hurting someone. Visitors who hurry to open the clear plastic door before the bucket is back at the bottom find it stops where it is and resumes its downward movement only when the door is again closed. This discovery has sparked a series of activities involving the interlock: visitors investigate how fast it works, if they can beat it, and where the electrical contact is that makes the gizmo work.

The two most elaborate areas of the activity center—and the ones at which visitors spend the most time—are the solar-car workshop and the "Midden Mystery." The workshop's main activity is similar to part of the Oregon museum's exhibit "Engineer It!" Visitors assemble model solar cars at a long workbench with room for many people to work at once. They can experiment with wheels of three sizes. They can adjust the tension on the rubber-band pulley that connects the solar-powered electric motor to the drive axle. They can move the motor and make a front-wheel-drive or rear-wheel-drive vehicle. And by turning their vehicles upside down on a bench with embedded lights—to activate the solar cells—they can check at any time how the wheels spin. Visitors can also take their cars to a test track where variable light controls and automatic and manual timers allow an entire group to have a role in a test run. For people who are interested, challenge cards suggest activities beyond how to make cars simply work or go as fast as possible. For instance, one idea proffered is to figure out how to run the course in exactly 12 seconds, which usually means slowing down the vehicle.

"Midden Mystery" focuses on drawing conclusions. A midden is an archeological garbage dump. Ours, of course, is simulated; it resembles a large sandbox filled with crushed walnut shells. (They don't stick to skin and clothes as sand does.) Questions such as "What did the inhabitants of this site do here?" are placed nearby. As visitors brush away the "sand," they find in it shells, animal bones, arrowheads, and other stone tools. THey also discover some fiber-cast objects, such as of an animal skeleton, embedded in harder layers below.

Near the dig site are workbenches for measuring, recording, bagging, and posting information about the finds. Visitors can speculate on what the objects may have been used for and can take them to tables with reference collections of mollusk shells, small mammal bones, and various stone tools, and they can compare their ideas with experts' opinions that have been left on answering machines at two "curators' desks." Finally, visitors can "publish" their theories using a computer terminal outfitted with a miniature video camera and a microphone, and can learn about other museum-goers' results and conclusions.

We have purposely built many such reporting mechanisms into "Investigate!" We want visitors to be able to leave behind their questions, speculations, observations, measurements, and conclusions for others to learn from. The idea in that activity center is to supplement the educational voice of the museum to illustrate the idea that scientific truth is determined not by authority but by evidence. We are finding that only a small fraction of visitors record detailed conclusions, but nearly everyone contributes answers to limited questions posed on computer terminals throughout the exhibit. These answers become part of growing databases. We are also learning that strangers frequently talk with one another about matters far more detailed than "What does this do?" Questions such as "How did you get this to happen?" arise.

The activities in "Investigate!" actually constitute the Boston museum's second activity center. The first center was much simpler, representing our initial foray into the new approach. The activities in "The Observatory," which tend to be less complex, are designed to encourage museum-

goers to become aware of their observational skills. In one area a visitor can operate a remote camera aimed at a terrarium to take a close look at, say, a lizard's eye or a giant Madagascar cockroach. Another activity is designed for two people to play with emitting and detecting sounds from any of 12 overhead speakers. We are now drawing up plans for the other four activity centers.

Other science museums are moving in a similar direction. When "Investigate!" opened this year, staff from 21 other science centers attended a workshop to examine that exhibit and the way it was developed; many were already making similar plans.

Science museums have a critical role to play in complementing what students learn in school.

Patrons of the Art

The scientific process is at the center of the latest U.S. effort to reform the teaching of science from kindergarten through grade 12. A pivotal 1989 report published by the Educational Testing Service revealed that U.S. students lagged behind other students not in their knowledge of scientific facts but in applying thinking skills to solving problems. A month later, *Science for All Americans*, a report based on a three-year study by the American Association for the Advancement of Science, called for massive changes in the way science is taught to emphasize "exploration of questions" and critical thinking over "learning of answers." Clearly, science museums have a critical role to play in complementing what students learn at school.

Thus the National Science Foundation, which has funded activities throughout the United States aimed at improving science education, has supported the growth of innovative museum exhibits: NSF's Informal Science Education (ISE) grant program has become an important source of funding for such exhibits. The program not only enables specific institutions to create new offerings but also encourages developers to communicate with other educators. To ensure that others will learn about what succeeds and fails, NSF requires evaluations and dissemination of information about museums' programs.

Recently cuts have been proposed for ISE, including a 30 percent cut for the federal fiscal year of 1997. Fortunately, recognition among members of Congress of the value of informal education prompted the Senate Appropriations Committee to restore funding during the 1997 budget review process.

In such a climate, however, science centers clearly cannot depend on just this source of funding to advance their new educational goals. The private sector also needs to broadly support innovative exhibit development. Sadly, economic reality has caused corporate philanthropic contributions from U.S. businesses to decline in recent years. Interested in attaching corporate names and sometimes logos to projects, companies' marketing departments are partly replacing the older form of support. But these branches are less likely to invest in experimental and therefore risky projects.

With just a few museums having created activities that emphasize the process of science, developers have only begun scratching the surface on this powerful and potentially influential concept for effective and enjoyable "informal education." To help develop such approaches, all those with a stake in science education need to step up and do their part.

Forum

By Michael Krepon

Time to Push Weapons Treaties—Not Block Them

Agreements banning chemical weapons and halting nuclear testing await Senate ratification. President Clinton and the Republican Senate need to rise above politics to pass these much-needed measures.

President Bill Clinton's legacy on reducing weapons of mass destruction will be decided by a U.S. Senate controlled by Republicans. At stake is the ratification of two treaties essential to devaluing weapons of terror and isolating states that wish to flaunt them: the Chemical Weapons Convention (CWC) and the Comprehensive Test Ban Treaty. Depending on the outcome of Senate ratification, Clinton and his new team can either build on the successes of his first term or go down in history as the president on whose watch critical treaties went unratified and promising post–Cold War initiatives foundered.

Last September, Republican irreconcilables in the Senate blocked the CWC, despite this accord's direct descent from efforts in the Reagan and Bush administrations. Another successful blocking action against CWC in Clinton's second term would not only shelve that accord but also effectively kill prospects for ratifying the Test Ban Treaty: the Clinton team, not wanting to risk two punishing treaty defeats, would probably withdraw the test ban from consideration.

In this century only two major treaties have died because of irreconcilable Senate opposition: the League of Nations Covenant, signed in 1919, and the second Strategic Arms Limitation Treaty (SALT II), signed in 1979. Both treaties sank largely because of the opposition of an ambitious Senate Republican leader. President Woodrow Wilson, who championed the League, clashed with Henry Cabot Lodge; Jimmy Carter withdrew SALT II from consideration after the Soviet invasion of Afghanistan ended all hopes of convincing Senate Minority Leader Howard Baker to support the treaty. Much is therefore riding on Clinton's ability to work with new Senate Majority Leader Trent Lott—just as President John F. Kennedy persuaded a skeptical Republican Senate leader, Everett Dirksen, to swallow his reservations and support the Limited Test Ban Treaty in 1963.

The odds for ratification seem to favor President Clinton. Most treaties pass the Senate with votes to spare, and no powerful constituency is clamoring for the right to develop, produce, and use chemical weapons—the activities the CWC would ban. The Comprehensive Test Ban Treaty, which would end the testing of nuclear weapons and the production of new warhead designs, has also garnered widespread public support. Nevertheless, the administration yanked the CWC from Senate consideration last fall after Lott joined Republican presidential candidate Bob Dole and Senate Foreign Relations Committee Chair Jesse Helms in opposition. This triumvirate questioned the treaty's utility, given the likelihood that some states presumed to have chemical weapons, such as Iraq and North Korea, would not ratify it. The Republican leadership also expressed grave reservations about the adequacy of verification provisions.

The requisite 65 countries have ratified the CWC, so the treaty will go into force April 29 no matter what the United States does. But American participation matters. Unless the U.S. Senate votes to ratify, we will sit on the sidelines. So will Russia and China, who are waiting for Washington's decision. Without participation by the United States and Russia, with their combined chemical weapons stockpiles of more than 70,000 tons, the CWC will be a hollow shell. And without U.S. inspectors and U.S. leadership, the ban will be ineffective.

Years Lost to Partisanship

Supporters of the CWC were disappointed by the Clinton administration's lack of urgency in pursuing treaty ratification. During Clinton's first year in office, treaty supporters were the primary culprits, seeking an expansive prohibition on riot-control agents as "a method of warfare." Overriding Pentagon qualms, the administration decided that the CWC would not allow tear gas use for some humanitarian purposes where combatants and noncombatants are intermingled, such as rescuing downed air crews. It took ten months to resolve this issue and to send the treaty to the Senate.

The administration's second year was lost to treaty ratification because of

ILLUSTRATION: CHRISTOPHER BING

White House passivity and a leisurely Democratic-led Senate review of the treaty. When phone calls were desperately needed by the president, vice-president, and secretary of state to move the CWC onto the Senate floor in the second half of 1994, none were solicited or made.

In 1995 and 1996, with the Republicans in control of the Senate and the presidential campaign under way, the CWC's prospects dimmed further. Jesse Helms, a staunch opponent of the treaty, became chair of the Foreign Relations Committee. Bob Dole's departure from the Senate to run for president gave the Senate's reins to the much more partisan Lott. Then in the heat of his doomed candidacy, Dole accepted hard-right advice to deny Clinton the photo opportunity of a treaty ratification ceremony. With the Republican presidential nominee and its Senate Majority Leader both firmly opposing ratification, prospects for securing the necessary two-thirds vote were uncomfortably thin. The Clinton team wisely decided to pull the CWC and fight another day.

Unfortunately, the new Senate is notably lacking in moderate Republicans with sufficient standing to elevate treaties above partisanship. Unless overridden by Majority Leader Lott, Helms is likely to stonewall the CWC. Irreconcilable treaty foes will again use the tactic of attaching "killer amendments." Last September, Lott joined Helms in demanding that the U.S. intelligence community certify that it could monitor treaty compliance with "high confidence" before the treaty could be approved. Even with the CWC's unprecedented inspection provisions, such confidence is impossible to guarantee. The Republicans will also try to block the nuclear test ban, which—lacking the Reagan-Bush imprimatur of the chemical treaty—engenders even fiercer GOP opposition.

There is no secret to a successful ratification campaign. One key is to avoid at all costs a partisan divide. Successful presidents work hard at lining up the support of key senators early rather than waiting for the eleventh hour. President Wilson lost his crusade for the League of Nations—a popular idea in post–World War I America—because he made it a partisan battle. Wilson kept Senate Majority Leader (and Foreign Relations Committee Chair) Lodge at arm's length during negotiations and refused to enlist the help of any Republicans of stature.

Making the Case

The president could enlist many high-ranking Republicans, such as key GOP senators past and present; former Bush administration officials, such as National Security Advisor Brent Scowcroft, Secretaries of State James Baker and Lawrence Eagleburger; and even President Bush. But such top Republicans won't carry the administration's water unless the president, vice-president, Secretary of State Madeleine Albright, and Secretary of Defense William Cohen personally go to bat for the treaty.

Clinton will also have to rely heavily on top Pentagon officials and military brass to make the case for ratification. Skeptical Senators will need to receive intelligence briefings that reassure them about the ability to monitor the treaty and that stress how much worse the problem of chemical weapons proliferation would be without the CWC. Important friends and allies such as Israel could be enlisted to help make the case with selected senators that the best way to deal with stragglers and nonsignatories is to get the CWC up and running.

Another key advocate of the CWC is the Chemical Manufacturers Association, which was active in last fall's ratification debate and was sorely disappointed with the administration's eleventh-hour effort. The association is again ready to remind Republican senators that failure to ratify CWC could mean the loss of thousands of domestic jobs, since the treaty imposes penalties on trade in chemicals used to make weapons with countries that have not ratified. If the United States refuses to join the convention, production would therefore shift to countries that are members in good standing.

A second key to success is to shape the terms of debate early and often. The president must speak to the nation forcefully and consistently about his administration's goals in reducing and eliminating weapons of mass destruction. Successful presidents clarify the stakes involved in a Senate's vote; Clinton needs to explain the damage that would result to nonproliferation and anti-terrorist efforts if the Senate blocks ratification.

Finally, Clinton must make every effort to come to an accommodation with the Senate Majority Leader. He must seek to assuage Lott's concerns without accepting crippling Senate conditions to ratification. Clinton could make sure that Lott is deeply involved in efforts to ensure effective compliance, while agreeing to send periodic reports to the Senate explaining how compliance concerns are being addressed. Rather than insisting upon the participation of all troublesome states, the Senate might be persuaded to condition U.S. ratification on the explicit right to demand withdrawal if a majority of senators believe that the treaty's value is outweighed by the nonparticipation of key countries. It is better to accept the treaty with such an escape hatch than to reject it outright.

Trent Lott has a difficult decision to make, and the outcome of his deliberations will do much to shape the attitude of the Republican party toward international affairs. Lott has the power to kill treaties. But at the end of the day, he must choose whether to align the Republicans with irreconcilables like Jesse Helms or to reinforce a long history of Republican presidents and secretaries of state who have planted the flag of American leadership abroad. If Lott sides with Helms's brand of isolationism, he is likely to damage U.S. national security as well as his party's political prospects. ■

MICHAEL KREPON is president of the Henry L. Stimson Center in Washington, a nonpartisan organization specializing in arms control and international security. He is co-editor of The Politics of Arms Control Treaty Ratification *(St. Martin's Press, 1992).*

It's Morning in American Industry

The U.S. has regained strength in businesses ranging from steel to semiconductors as companies adapt to the government's ability to form productive commercial partnerships.

ROBERT M. WHITE

PRESIDENT Clinton won reelection in large measure because of the economy. Unemployment is the lowest in decades, inflation is low, GNP growth is steady, and the stock market is at historic levels. The lamentations of the 1970s and 1980s about the competitive decline of U.S. industry have disappeared from the political rhetoric. How to account for this turnaround?

The United States is prospering in the global technological economy because it is effectively employing the world's diverse resources. Most products are assembled from parts made in many different countries. Boeing aircraft, for example, are assembled in Seattle out of key components fabricated in Japan, Korea, Israel, and elsewhere. General Electric assembles washing machines in a highly automated plant in Louisville, Ky., but the electronics come from Mexico.

Just as corporations tap the financial and manufacturing capabilities of other nations, they also tap their intellectual resources to develop competitive products and services. Today over 15 percent of all company-financed R&D in the United States is performed by American subsidiaries of foreign-owned companies. In turn, U.S. companies perform some $10 billion of R&D abroad.

Although some feel that the creative fruits of American R&D are being exploited by other countries, a recent report from the National Academy of Engineering belies this view. The academy concluded that "any country, including the United States, should welcome R&D activity within its borders, regardless of the nationality of the R&D performer." Foreign-funded R&D expands the pool of basic knowledge, facilitates the transfer of technology to the United States, and employs American scientists and engineers.

The global interweaving of production and R&D has its downside, of course, such as the migration of jobs overseas. Wages are lower in many countries for everyone from production workers to scientists and engineers; computer programmers in India and Bulgaria earn one-tenth the salary of U.S. programmers. Still, the countervailing tendency of foreign companies to have their U.S. subsidiaries take on production, marketing, and R&D offsets this outflow of jobs.

What's more, over the past decade, key U.S. industries have maintained and broadened their world-competitive position and others have been newly established. The semiconductor and automobile industries, in particular, are once again competitive. The communications, software, entertainment, pharmaceuticals, chemicals, and energy industries are also thriving—though in many cases the boom has come only after painful corporate restructuring and downsizing.

U.S. prosperity can be attributed in part to enlightened economic and trade policies, a national commitment to investment in science and technology, and a continuing determination to fund graduate-level science and engineering education. But the most fundamental reason for the success of the U.S. economic system is its ability to take advantage of new technology and adapt to competitive challenges.

The car industry is a good example. Japan used lean manufacturing and the development of high-quality, fuel-efficient vehicles to capture a large share of the U.S. automobile market. But U.S. automakers have since responded with their own version of efficient manufacturing processes and also produce high-quality products. And when the U.S. steel industry became uncompetitive in world markets, companies imported new steelmaking technology from abroad and devised some of their own. Minimills in the United States now produce specialty steel at the lowest cost per ton in the world.

And despite all the political bickering about the government's role in advancing the country's economic welfare, federal and state entities have proved capable of pragmatic action. When the semiconductor industry was in a competitive slump, new institutions such as Sematech, the consortium of chip manufacturers, were created as joint government/industry ventures, helping greatly to restore U.S. competitiveness. Other government/industry projects such as the Program for a New Generation of Vehicles—established to produce radically more fuel-efficient automobiles—are looking not to catch up but to leapfrog ahead. Less ambitious but equally important public-private partnerships abound, encouraging innovation in a host of industries.

The United States is on a competitive high. But other countries race to catch up. Japan is doubling its investments in basic research. China and Southeast Asian countries are moving at warped speed to become global technological competitors. The United States will therefore surely suffer economic ups and downs in the years ahead. But in the words of baseball great Satchel Paige: "Don't look back, something may be gaining on you." We need to continue learning—and faster than the competition can emulate us. ■

ROBERT M. WHITE, president emeritus of the National Academy of Engineering, is senior fellow at the University Corporation for Atmospheric Research and at the H. John Heinz III Center for Science, Economics, and the Environment.

PHOTO: CLAUDE VAZQUEZ

Electronically Implanted "Values"

Internet filtering software, promoted as a way to make the Net safe for children, can easily become an insidious tool for promoting a political viewpoint.

LANGDON WINNER

LAWS, regulations, police, education, propaganda—these are among the means societies have traditionally employed to promote and defend the values they deem crucial. Yet these efforts are now challenged by the vast possibilities for misbehavior that arise in today's networks of electronic communications. People end up seeing pictures, reading words, and indulging in activities that sometimes depart from prevailing community standards. The growing response to these mischievous practices is to implant prohibitions within the electronic hardware and software itself.

One example is the V-chip, the device that television manufacturers must now build into every set sold in the United States. The V-chip will enable set owners to block programs with excessive violence or sex. Proponents of the V-chip, including President Clinton, hope it will allow parents to control the kinds of scenes their children see on television.

While giving families power of this kind is a positive development, the V-chip addresses only certain kinds of concerns. For example, many parents I know worry not only about the killing, brutality, and prurient sexuality that abounds on the tube but also the barrage of advertisements that push hollow consumerism as life's central goal. The same technology that spawned the V-chip could also enable a C-chip—a device giving parents the choice of deleting the commercials that bombard kids for 10 minutes out of every half hour. Why is no one promoting such an innovation? (Don't write me. I know the answer.)

Another domain in which the implanting of certain norms is becoming commonplace is the Internet. The Communications Decency Act, now before the Supreme Court for a ruling on its constitutionality, makes it illegal to send indecent material over the Internet if children may see it. An alternative approach, one that many parents find appealing, involves the use of filtering software. A mini-industry has formed to sell products with names like Net Nanny, Safe Surf, and CyberPatrol. Parents can set these filters to block a computer user's access to Web sites that contain pictures of undraped bodies and the like.

It turns out, however, that the power of deeply embedded censorship can do more than weed out erotica. Recently it was revealed that one of the more popular smut blockers, Cybersitter, also makes it impossible for computers to access the home page of the National Organization for Women. Cybersitter was developed by SolidOak Software in close cooperation with Focus on the Family—a right-wing organization that has waged censorship campaigns seeking to remove books it finds objectionable from libraries and public schools. Thus, Cybersitter is actually an extension of Focus on Family's antifeminist, antigay, anti-abortion rights agenda.

The utility and seeming neutrality of the package has convinced companies that bundle software to include it in their packages. Do these companies and their customers know the political agenda that they are buying into? SolidOak doesn't conceal its connection to Focus on Family, but it doesn't advertise it either.

Other filters have also overstepped their advertised purpose. Animal rights and environmental groups complain that CyberPatrol, made by Microsystems Software, blocks their sites because the news and pictures they present are deemed "gross depictions." CyberPatrol also denies access to the League for Programming Freedom (an organization that opposes software patents) and to some 250 newsgroups, including the distinctly non-pornographic offerings of alt.feminism and soc.support.fat-acceptance.

In addition to imposing a hidden political agenda, Cybersitter also encourages parents to spy on their children. As SolidOak's press release proclaims, Cybersitter can keep a "secret log" of Internet sites that a user visits, "making it easier for the parent to monitor their children's on-line habits." Other software filters offer similar recordkeeping features.

Products of this kind remind one of the totalitarian states earlier this century that tried to establish order by getting family members to spy on each other. Alas, the same practices could well greet parents when they go off to work. Employers can now deploy programs such as Web Track and Sequel Net Access Manager to monitor their workers' Internet activities and to block access to sites that might detract from productivity.

Both the V-chip and Internet filters reflect today's tendency to respond to legitimate worries with technical fixes. But citizens of cyberspace must learn to identify, criticize and, when necessary, resist the deeply embedded codes in these "protective" devices. Software purchasers should loudly denounce products that try to smuggle in repressive social agendas or limit free speech. Advocacy groups that find themselves blocked by cyberfilters must similarly seize this issue as part of the causes they advance. We must not allow the new technology to become a covert carrier of highly dubious regimes of virtue. ■

LANGDON WINNER is director of graduate studies in the Department of Science and Technology Studies at Rensselaer Polytechnic Institute. His e-mail address is winner@rpi.edu and his home page is www.rpi.edu/~winner/winner@rpi.edu.

PHOTO: L. BARRY HETHERINGTON

Reviews

BOOKS

REASONS FOR LOVING NATURE

The Value of Life: Biological Diversity and Human Society
by Stephen R. Kellert
Island Press, $24.95

BY HOLMES ROLSTON III

STEPHEN Kellert has spent his life researching what people think about natural resource conservation, and *The Value of Life* is the result, presenting findings not only on Americans but on Germans, Japanese, and Botswanans. What the author reveals is that people vary widely in their response to the natural world, and that the ways in which they vary show just how much nature has to offer us.

The nine categories of values Kellert has designated are themselves illuminating. They include "utilitarian" values, which lead people to think of natural resources as goods to be tapped; "naturalistic" values, which center on positive physical, emotional, and intellectual encounters with the nonhuman world; and "ecologistic-scientific" values, whose focus is the patterns, structures, and functions in nature. "Aesthetic" values are evident when people find beauty in the natural world. Those with "symbolic" values use nature for communication and thought in stories, myths, and figures of speech, while those with "dominionistic" values see nature as a challenge—for example, as a mountain to be climbed or a wilderness to be braved. "Humanistic" values come into play when something of a one-on-one relationship develops, as when people bond with pets. Finally, "moralistic" values focus on right and wrong conduct toward animals and nature, and "negativistic" values are at work when people hate denizens of the natural world such

as snakes and spiders. Comprehensive as this list of categories may seem, researchers in Botswana have had to add a tenth one, "theistic values," to refer to the views of indigenous people who attribute conscious life to phenomena in nature.

Kellert reports on how urban people differ from rural ones, young from old, well-educated from less well-educated, loggers from environmentalists, hunters from humane-society members, birdwatchers from zoo visitors, TV watchers from backpackers. The author is, moreover, careful and insightful in interpreting his results, always with an eye to explaining the perspectives of various respondents. For instance, in noting that the Japanese have relatively little interest in conserving biodiversity, he reflects that this may be because they largely enjoy nature culturally transformed into an artform, often as an avenue of escape from the workday life. They are, in other words, more likely to be moved by flowers skillfully arranged in a vase than by uncultivated vegetation in a field, fed upon by animals.

But in the end, *The Value of Life* is not a book about how people differ. On the contrary, what Kellert really hopes to find is a human tendency toward "biophilia," the term Harvard entomologist Edward O. Wilson has invented to describe an innate, transcultural disposition: by human nature, we love nature, according to this view. And conservation based on such "hereditary needs of our species" is seen to be on solid ground.

Selfish Genes

Kellert has to conclude, however, that there are but "weak biological tendencies" toward biophilia. Cultural "learning and experience exert a fundamental shaping influence on the content, direction, and strength" of the values he has defined, he writes. For instance, adult respondents with only a sixth-grade education have very high negativistic attitudes toward nature; those with some graduate education evince very low negativistic attitudes. Most Botswanans think that intervening to save wildlife may bring the wrath of the gods; educated Botswanans form a "striking exception" to the general view.

There is, in other words, as much diversity about biodiversity as there is biodiversity. Yet Kellert is still determined to make his argument that "underlying values remain constant." Thus after eight chapters that survey the riches biodiversity offers us by examining the vast array of human responses to it, Kellert, in a ninth chapter on education and ethics, concludes his book quite bluntly. "Every person possesses the ability to mine this creation and thereby enrich his or her experience," he tells us. "This represents the ultimate self-interest of an ethic of respect and reverence for the value of life." The author stretches toward a vision of richness for 200 pages and then backs away in the last sentence, collapsing everything into our "ultimate self-interest."

The truth seems to be that the biophilia hypothesis is connected with the sociobiological hypothesis, also made famous by Edward O. Wilson. And within the framework of this particular theory, all phenomena, whether in nature or culture, is interpreted in terms of self-interest. Our deepest motivations are always buried in our selfish

ILLUSTRATIONS: BRUCE P. MADDOCKS

genes. But over the centuries, philosophers have seriously questioned the idea that ethics can be reduced to enlightened self-interest, and those classical worries return to bring doubt about whether an adequate environmental ethic can hold that humans should value nature only for what they can get out of it.

Kellert can say that he is enlarging the category of self-interest, and indeed, there is nothing narrow about his thinking; he wants all 10 million or so species embraced in "a broad anthropocentric ethic of life." Still, it never seems to sink in that such ever-enlarging self-interest would "ultimately" (to use his word) pass over into something else—into a respect for life in which people would value something other than their personal well-being.

Interestingly, the results of a six-year study sponsored by the National Science Foundation and documented in *Environmental Values in American Culture* by Willett Kempton et. al. (MIT Press, 1995) suggest that such a mindset is not uncommon. Testing the claim that "we need to be as fair to plants and animals as we are towards people," the study found agreement not only among 97 percent of Earth First members but also among 63 percent of sawmill workers from the Pacific Northwest. And even Kellert's own research points to the conclusion that human beings are not entirely consumed by self-interest. Again and again, people have registered for him a value "especially associated with concern for the ethical treatment of animals and nature"—a value whose "more central focus is right and wrong conduct toward the nonhuman world." Might this mean that people find intrinsic value in nonhuman life? Doubtful, thinks Kellert. The "highly abstract notion of awarding all species an inalienable right to exist" is too weak to motivate people into "denying their own self-interest," he says.

But it is at least worth considering that what is needed to preserve biodiversity is not better surveys detecting biophilia in our selfish genes but moral vision and courage. And it is also worth considering that such qualities may already be more widespread than Kellert is prepared to realize. To be sure, *The Value of Life* is an excellent and important work. It is the best account available of the good reasons for preserving biodiversity, which are reflected in the values of millions of people. Would that Kellert could also have envisioned the best reasons, and perhaps found these operating in the values of people, too.■

HOLMES ROLSTON III, professor of philosophy at Colorado State University, is the author of Environmental Ethics *(Temple University Press, 1988).*

BOOKS

FLYING THE MULTINATIONAL SKIES

Turbulent Skies: The History of Commercial Aviation
by T.A. Heppenheimer
John Wiley & Sons, $30.00

BY THEODORE L. GAILLARD, JR.

IN *Turbulent Skies: The History of Commercial Aviation*, freelance aviation and science writer T.A. Heppenheimer traces the bumpy flight path of the U.S. airline industry's development—from the people who took the lead to the innovative technologies that allowed them to do so; from the early years of a cocoon-like cartel to the chaotic free-for-all following deregulation. Along the way, the author offers exciting stories of pioneers and visionaries like Charles Lindbergh, whose 1927 solo flight across the Atlantic fanned interest in passenger flying; Walter Brown and other postmasters general, who awarded lucrative subsidies to air mail routes, thereby encouraging airlines to grow; and American Airlines's C.R. Smith, who spurred Donald Douglas to manufacture the DC-3, the craft that—as Smith himself would say—"freed the airlines from complete dependence on mail pay. It was the first airplane that could make money just by hauling passengers."

Heppenheimer's account of the technological developments that helped the industry to evolve is enlightening. He notes, for example, that a key factor in enabling early airlines to replace mail with more passengers was the development in 1926 of Pratt & Whitney's *Wasp* engine, which could generate more power with less weight. Then, between 1933 and 1936, came the twin-engine revolution: faster, more easily main-

tained Boeing 247s, Douglas DC-2s, and, finally, the DC-3.

Nor does the author neglect the growth of the airlines's infrastructure. After World War II, air travel took off in the United States thanks to pent-up demand, the ready availability of military-trained pilots, and the larger, faster transport aircraft developed during the war. But, as Heppenheimer points out, there weren't enough airports, and effective air traffic control was in its infancy. He does a masterly job of outlining corrective measures instituted by the Civil Aeronautics Board and the Federal Aviation Administration—more stringent flight regulations, the use of radar, and the installation of collision-avoidance systems.

Nevertheless, *Turbulent Skies* contains baffling omissions, given the expectations fostered by its subtitle. Except for side glances at jet engine development, the *Concorde* supersonic airliner, and competition between Boeing and Europe's Airbus Industrie consortium, the book offers primarily a history of the U.S. airline industry alone. Interesting and competent, yes, but a globally oriented "history of commercial aviation" it is not.

A Cloudy Crystal Ball

A real history of the type Heppenheimer has purported to write would have included a comparative summary of the growth of major international flag carriers such as Air France, Lufthansa, and BOAC, whose *Comet* was in 1952 the first jet airliner to enter service, and whose descendant, British Airways, now owns 25 percent of USAir. The former Soviet Union's achievements in commercial aviation also deserve a mention—for example, Aeroflot was at one time the world's largest airline and the first to fly a supersonic airliner, its Tu-144 lifting off two months before the British/French *Concorde*.

Heppenheimer never talks about the explosion of air travel markets in the Pacific Rim, or the proliferation of start-up airlines in such new centers of tourism and expanding industry as Africa, West Asia, and Australia. We read of rapid postwar growth problems

in U.S. air travel but nothing of the difficulties Europe has faced because of rigid ticket pricing, bad weather, and crowded skies. And except for a brief account of the founding of Federal Express, *Turbulent Skies* fails to discuss the world's booming air freight industry.

The worldwide transition from piston to turbojet engines is similarly conspicuous by its absence. During the period when jet engines were not powerful, reliable, or fuel-efficient enough for commercial use, the industry employed turboprops, a technology in which smaller jet engines drive propellers. The result was airliners that were faster than prop aircraft yet more fuel-efficient than military jets. But Lockheed's turboprop *Electra* is barely mentioned, even though 127 *Electras* flew with six major U.S. carriers, as did 88 British *Viscount* turboprops, which also served in many other airlines throughout the world. In fact, numerous turboprop designs still ply shorter routes in ex–Warsaw Pact countries, and cost-effective turboprop twins now dominate the U.S. "feederline" markets that connect smaller airports with major airlines's hub cities.

Finally, Heppenheimer projects that, worldwide, airlines will be placing orders for almost $1 trillion in new aircraft over the next 15 years, but he neglects to mention how the growing viciousness of global competition has forced U.S. companies to team up with foreign manufacturers. For example, McDonnell Douglas and Boeing have forged subcontracting arrangements with China and Japan in the scramble for crucial Pacific Rim orders. And GE has joined with SNECMA, France's engine manufacturing giant, to produce the CFM-56 turbofans on late-model Boeing 737s, as well as larger derivatives used by other aircraft around the world.

Yet despite all that is missing from *Turbulent Skies*, Heppenheimer's closing account captures some of the intertwined swirls of excitement and anxiety that cloud the crystal balls of airline forecasters. Yes, annual industry revenues now exceed $200 billion worldwide. Yes, still-rising passenger demand and the vast distances of an expanding Pacific Rim market may well prompt the launch of an 800-passenger jetliner as well as a second-generation supersonic transport that is bigger, more environmentally friendly, and more profitable than the *Concorde*. But even so, unprecedented development costs will impose tremendous financial risks. Who will get the orders—Boeing, Airbus, a multi-company U.S. team, or an expanded European consortium that includes Russia's Tupolev or Antonov design bureaus? Will they drive one another into bankruptcy?

To complicate matters further, we are now witnessing the beginnings of airline deregulation in the countries of the European Union. Will the outcome echo the chaos the U.S. industry experienced in 1978? And on the other side of the world, what impact will recurring political disagreements with China and trade rivalries with Japan have on aircraft orders from those two regions—or on the flow of their jetliner subassemblies to U.S.-based manufacturers? The outlook is not optimal—not what fighter pilots once called CAVU: ceiling and visibility unlimited. Thunderheads of uncertainty mass on the horizon. The seat belt sign may be off for now, but it may not be long before it goes back on again.■

THEODORE L. GAILLARD is a freelance writer specializing in aviation and military technology.

CONTINUED FROM PAGE 10

LEARNING FROM TV WEATHER WONKS

Fred Gadomski, the meteorology instructor who is profiled in Steve Mirsky's "Turning Weather Wonks into TV Stars" (*TR November/December 1996*), and his like-minded colleagues deserve praise for their attempts to fashion weathercasting into a credible yet entertaining enterprise. Turn to many local and most network weather programs and you'll find there is much to accomplish. Part of the blame falls on the rigorous math and physics requirements for meteorology majors. They graduate with their heads in the clouds. Broadcasters facing dwindling audience shares are also at fault. Luring viewers is more important than offering a professional weathercast.

Gadomski describes the appearance of telegenic but scientifically untrained Ken or Barbie dolls doing the weather, especially during serious weather episodes, as "almost irresponsible." *Almost?* With extreme weather annually contending for the top economic disaster spot, weather people are crucial to viewers who sometimes need to make life-or-death decisions based upon the forecast.

Even when skies are blue, other topics such as the greenhouse effect, ozone layer depletion, and air pollution require evaluation and dissemination. Broadcast meteorologists are frequently the likely conduits of this information. Often the only people on the news staff with a scientific background, their perspective is important. So is their delivery. Analogies, comparisons, graphics, and metaphors enhance forecasts and enable the vast numbers of scientific illiterati on the other end of the tube to better understand.

However, I am not convinced that all these techniques can be learned in the classroom. Physics *and* liberal arts *and* social interaction are all necessary experiences that beget optimum communication in this improvisational setting. Other disciplines should sit up and take notice. Interpreters so armed can make science sing.

BRUCE SCHWOEGLER
Meteorologist/Science Reporter
WBZ-TV Boston

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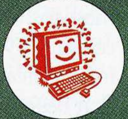

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TECHNOLOGY REVIEW
CAREERS

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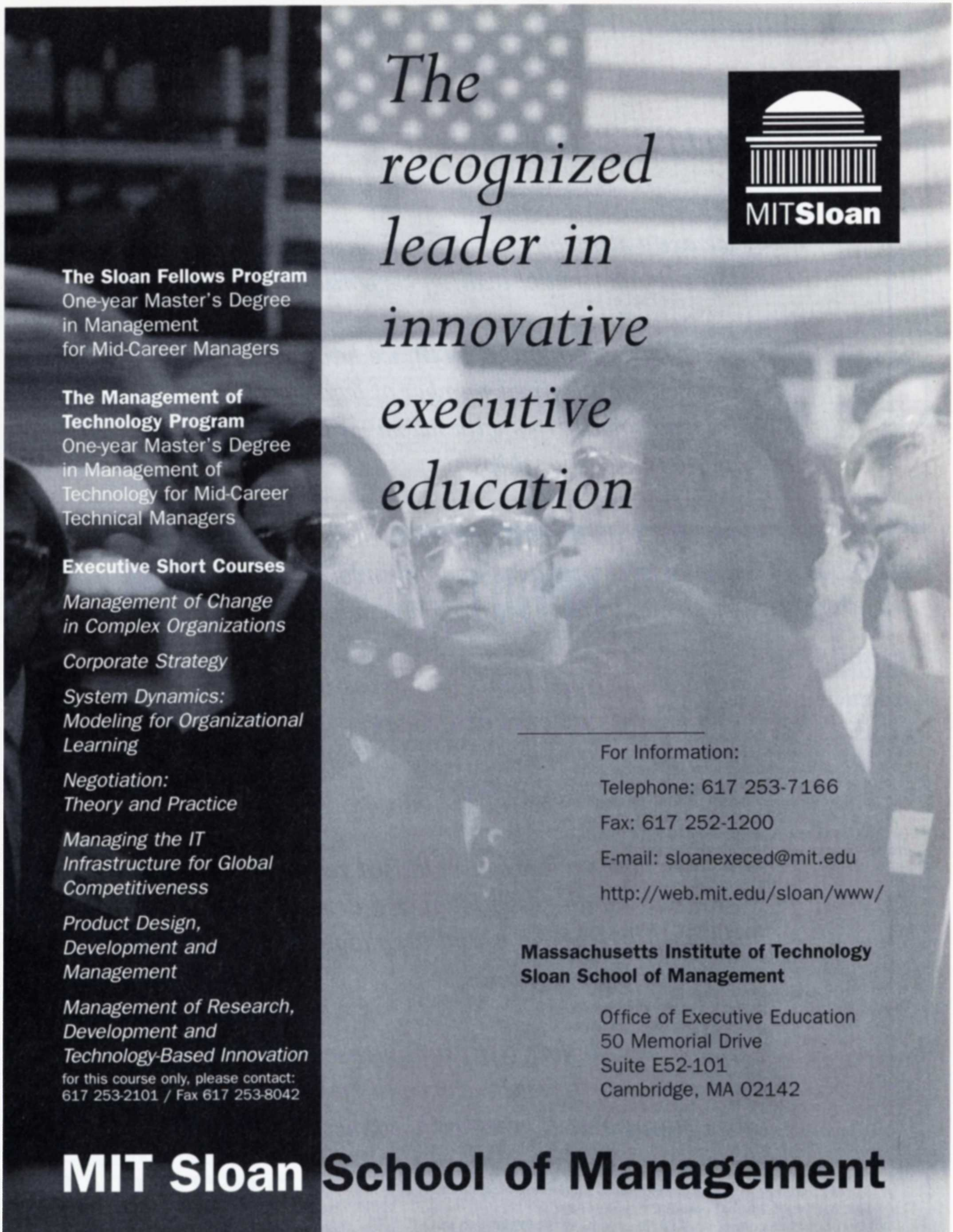
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SHE'S A DOCTOR TODAY BECAUSE HER ROLE MODELS WEREN'T MODELS.

She's delivered babies in rural South Carolina, performed surgery while on the Crow Indian Reservation in Montana and treated tropical diseases in West Africa.

Dr. Nicole Lang is a role model for girls today thanks to the role models she had growing up — parents and a grandmother who were education advocates.

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Database Marketing Services

DIRECTOR, MARKETING RESEARCH

In this position, you will be responsible for articulating & executing a world class vision for account planning and market research. We're looking for someone who invents, innovates and stays aware of new techniques. Our goal is to grow our research capabilities in support of Account Management in planning new business development, adding significantly to the revenue stream. Our ideal candidate will develop and manage a department of marketing research professionals with expertise in the areas of primary and secondary research, investment analysis, test design, statistical techniques, and other analysis. Master's degree required (Marketing or a related subject). Minimum of 10 years' experience required.
(Job Code: DMR/MIT)

BUSINESS TECHNOLOGY/ DATABASE MARKETING CONSULTANT

The successful candidate must have information technology/database marketing consulting and marketing expertise. Large scale project planning and management expertise in client management, including proposal through delivery. Master's degree desired (Marketing, Technology, Business or combination). At least 8 years' professional expertise with particular emphasis on strategic business, database marketing and information technology issues with client sight implementation of technologies and processes. **(Job Code: BT/DMC/MIT)**

Management Consulting

DIRECTOR, CUSTOMER SUPPORT MANAGEMENT

Evaluates and recommends client capabilities to deliver superior integrated customer support across direct customer-facing channels including sales, fulfillment, customer service, technical support, billing and collections in alignment with Customer Based Management. MBA with 10+ years in customer relationship management focusing on marketing, customer service/sales within an integrated channel environment. Infrastructure re-engineering (consulting) experience with Fortune 500 organizations preferred.
(Job Code: VPMC/MIT)

MANAGER

Consults to Fortune 500 clients on customer solutions involving the integration of strategy, operations, organization and technology. Solves client issues using data analysis, interviewing and financial modeling techniques. Manages projects with cross-functional teams using established consulting methodology. Develops client proposals, work plans and deliverables. Sells add-on services to existing client base. Qualifications: MBA or Master's degree in related discipline; broad knowledge of 3-5 industries; 5-7 years' consulting experience; expertise in finance, operations, marketing and/or technology. **(Job Code: MMC/MIT).**

Teleservices

VICE PRESIDENT/ DIRECTOR TELESERVICES

Directs our teleservicing infrastructure assessment teams to evaluate strategy, planning, operations, reporting and financial analysis of client's teleservicing business units. 8+ years' experience in teleservices management or consulting along with inbound/outbound/VR experience. Extensive strategic, operational, and project management experience within an integrated, direct response teleservicing operation. Knowledge of teleservices emerging technologies and vendor management is required. Bachelor's degree, MBA preferred.
(Job Code: VPT/MIT)

SENIOR MANAGER

Provides consulting to clients in the strategic integration of the telephone-based communication channel in marketing, customer service and technical support applications. Bachelor's degree, MBA preferred. 5 years' experience in the telemarketing/consulting industry. Knowledge of tele-infrastructure development and operational costs. Strong experience in the development, implementation and management of customized call center solutions (inbound/outbound). Ability to create and implement an integrated systems architecture (telephony information systems and agent workstations) is also required.
(Job Code: SM/MIT)

Information Systems & Services

MANAGER APPLICATION DEVELOPMENT

We are seeking an energetic team player to direct planning, development, implementation and maintenance of internal and external client business systems. This person will develop a system architecture to support current and future business requirements which include both internet/intranet development, transition to a new Finance/HR system, development or purchase of applications that will support our existing 25% yearly growth - identifying and implementing new scheduling/calendar applications, E-Mail applications, Lotus Notes, etc. Must possess in-depth understanding of business practices and 5+ years' experience in business systems development in a client server environment, with a minimum of 2 years' experience in a supervisory role. Bachelor's degree in Computer Science preferred.
(Job Code: MAD/MIT)

Qualified applicants should send, fax or E-mail their resume, indicating Job Code to:

Bronner Slosberg Humphrey

Prudential Tower, 800 Boylston Street, Boston, MA 02199;
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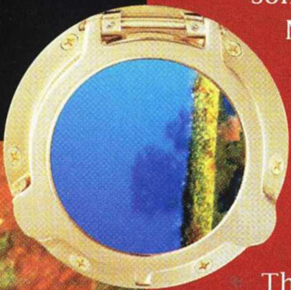

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HIGHWAY 1

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Summer, 1997 internship applications for Engineering & Technology also welcome. EOE/M/F/D/V